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OPTIMUM MACHINERY SIZES FOR CEREAL CROP PRODUCTION

by

GARVIN HERBERT KABERNICK

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Optimum Machinery Sizes for Cereal Crop Production" submitted by Garvin Herbert Kabernick in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

A computer model was built to simulate cereal crop production for the Red River Valley. Rainfall was simulated daily based on actual weather records. Seeding and harvesting dates were established on the basis of rainfall. Four seeding equipment sizes and three harvesting equipment sizes were tested with three different crops on four farm sizes. One hundred years of simulated farming was used to test each combination of seeding equipment size, harvest equipment size and farm size. Subsequent machinery costs and crop penalty costs were tabulated in the model and were used to predict the optimum machinery sizes for a given farm size.

The model indicates that the actual cost of owning any one of the four seeding equipment sizes for a particular farm size does not vary greatly. That is, all four sizes cost about the same on a per acre basis. In terms of penalty costs there is a risk of under sizing the seeding equipment. There is some interaction between seeding equipment size and harvest equipment size:

(1) harvest penalties are reduced slightly when oversized seeding equipment is used;

(2) undersized seeding equipment causes harvest penalties to appear relatively small on large acreages because the total acreage seeded is actually less than the farm size.

Oversizing of equipment does not appear to create a significant penalty. The use of the largest seeding and harvesting equipment on all but the smallest acreage does not create a significant increase in cost compared to the optimum machinery selection.

ACKNOWLEDGEMENTS

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1. INTRODUCTION AND OBJECTIVES

Farm machinery has become the major investment, excluding land cost, for grain farmers in Manitoba (14). The problem of deciding what size of machine to purchase for a specific function and a given land area has not been fully studied. Such a study must include variables such as: the operating and capital costs of machinery, machine capacities, effects of weather conditions on seeding and harvesting operations and the corresponding penalties involved.

The first objective of this study was to develop a model which would:

(1) simulate weather conditions for the area studied based on actual weather records,

(2) simulate the seeding and corresponding harvest operations for three kinds of crops under the influence of weather conditions,

(3) calculate the cost of owning and operating the seeding and harvesting equipment based on the acres of production and the capacity of the equipment,

(4) calculate the seeding and harvesting penalties based on machine capacity and the influence of weather.

The second objective was to calculate the average annual penalty costs and machinery costs based on one hundred years of simulated grain farming in the Red River Valley for all possible combinations of:

(1) four farm sizes,

(2) four seeding equipment capacities,

(3) three harvesting equipment capacities.

2. LITERATURE REVIEW

A number of people have attempted to predict the optimum machinery size for a farm operation or operations. These studies range from very intricate, detailed studies that involve small portions of the total system to broadly generalized studies that outline procedures for developing models. In this study an attempt has been made to combine these ideas and methods to entail the whole farming operation of seeding and harvesting of cereal crops to solve for the optimum machinery size for a given farm size.

The initial ideas for determining work days during the seeding operation were obtained from work done by Rutledge (23) who related weather and field tractability to determine the probability of obtaining work days for tillage operations in various parts of the Province of Alberta.

In the area of sizing and determining capacities of field machines the work done by MacHardy (15, 16), Von Bargen and Cunney (25), Donaldson and Webster (5) and Frisby and Bockhop (7) was useful. MacHardy (15, 16) used Lagrange multipliers to calculate the optimum size of field machinery where several machines are used in sequence. He also used Lagrange multipliers combined with linear programming in an iterative procedure to size machinery in relation to the whole farm plan. Von Bargen and Cunney (25) developed an activity ratio concept for use in machinery management studies. This concept has value in determining the effects of changes in activities upon the effective field capacity of a machine. Field capacity is dependent upon the crop, weather, a sequence of operations and operating policies. Timeliness and the number of acres determine the minimum field capacity needed. An operations analysis is used to select a tractor implement match followed by a cost analysis and timeliness of operation selection

procedure. Donaldson and Webster (5) used random simulation to find optimum solutions with respect to size and type of farm enterprises within resource restrictions. Frisby and Bockhop (7) used the model developed by Link (13) to calculate the optimum machinery system for corn production with respect to increasing acreage.

Holtman, et al. (8) illustrated a systematic approach by simulation of a corn harvesting system. Their method of calculating combine costs and capacities was useful in the development of methods to calculate machinery costs for this thesis. Combine costs and capacities were evaluated with a unique depreciation model which calculated depreciation by: straight line, straight line with 20 percent additional first year depreciation, double declining balance, double declining balance with 20 percent additional first year depreciation, sum-of-the-digits, and sum-of-the-digits with 20 percent additional first year depreciation. The model is capable of calculating annual depreciation by any one of these methods as well as comparing these on an annual basis. The model also uses variables such as weather amd subsequent field tractability and grain drying to determine harvest days. A comparison of acreages, sizes and combine sizes can be simulated to find optimum harvest capacity.

Penalty costs are calculated in this model to help determine machinery sizes. Beneditti and Frisby (1) developed a penalty cost model to assess penalty costs resulting from adverse field conditions and machinery failure. From these penalty costs machine replacement dates could be more accurately selected. Link (13) used a mathematical model to predict the effects of adverse weather and crop conditions on field machinery systems for a corn farm in Iowa.

The accuracy of the harvest simulation of this model owes much of

its credit to other authors. Campbell (2) investigated grain harvesting with respect to farm size, harvest capacity, dry and damp harvesting and subsequent preserving and storing methods, penalties and losses and related costs for specific locations in the Province of Alberta. MacHardy (17) also calculated harvest costs with respect to weather risk and subsequent penalties. Donaldson (4) investigated grain harvesting and weather risk with respect to harvesting capacity for farms in England. Russell (22) combined several computer programs to discover the optimum field machinery sizes for several locations in the Province of Alberta. Jeffers and Staley (10) used a mathematical model to demonstrate the relationship between machinery sizes, acreages and time available for performance of operations carried out in sequence in forage harvesting. Lievers (12) used a computer model to simulate forage handling systems to analyze the costs and benefits from the field to the feed bunk. Coupland (3) used CPM (Critical Path Methods) and PERT (Program Evaluation and Review Technique) to determine the interaction of crop conditions, productivity, and machine operation and reliability for forage harvesting operations.

The work that has been done in solving machinery sizing problem, whether for the production of cereal grains, corn or forages, has supplied many useful methods and ideas for simulation models for particular operations. These models once constructed can be applied to farm situations for practical economic results.

3. SCOPE OF THE MODEL

The amount of detail that could be incorporated into each grain farm operation is enormous. Unless some restraint is exercised to minimize input parameters the number of parameters becomes astronomical when looking at the whole operation of seeding and harvesting with respect to weather conditions, timeliness, penalties and the interaction of farm size and machinery capacities.

Therefore, the scope of this model is not to incorporate minor details which have little effect on the final outcome, but rather to use the major parameters which have the greatest effect on the optimum solution. Thus the decision was made to simulate the seeding and harvesting operations of cereal crop production under weather conditions for the Red River Valley based on actual weather records. Incorporated into this study were the interaction of several machine sizes, several farm sizes and subsequent capital, operating and penalty costs. Hopefully, then, the model will remain simple enough that others may use it for different land areas and other types of grain farming. It is the sincere desire of the author that the model will be used, altered and refined as the inputs become available as a result of further studies.

4. DESCRIPTION OF THE MODEL

The model simulates the necessary activities for the production of three cereal crops. Specifically, the activities are seeding, swathing and combining under the influence of rainfall. The variables are farm size and machinery size. The economics of the study are based on capital and operating costs of the machinery and penalty costs due to crop loss.

Figure 1 contains a flow chart of the logic of the model. The data for the simulation is initialized in the input blocks up to "read combining input parameters". From these the model is a yearly loop which calculates the total penalty and machinery costs for the year for as many years as desired. In this study, 100 years of farming was simulated for each machinery and acreage size studied. Tabulation of penalties and machinery costs takes place in the seeding, swathing and combining subroutines. The major step in the data initialization step other than reading values for input parameters was the calculation of rainfall probabilities as the basis of determining good and bad days. This is discussed in detail below. The major steps in the yearly loop were the simulation of the seeding process followed by the simulation of the swathing process followed by the simulation of the combining process. Note that this model assumes that labor is available to run the equipment when there is a good day so that one could be swathing and combining at the same time. Each step is discussed in detail below.

4.1 Rainfall Simulation.

The only weather parameter used is rainfall. Rainfall data are read into the model for the period May 1 to November 16 (200 days). The data are based on a 99-year daily average for Winnipeg and consist of the

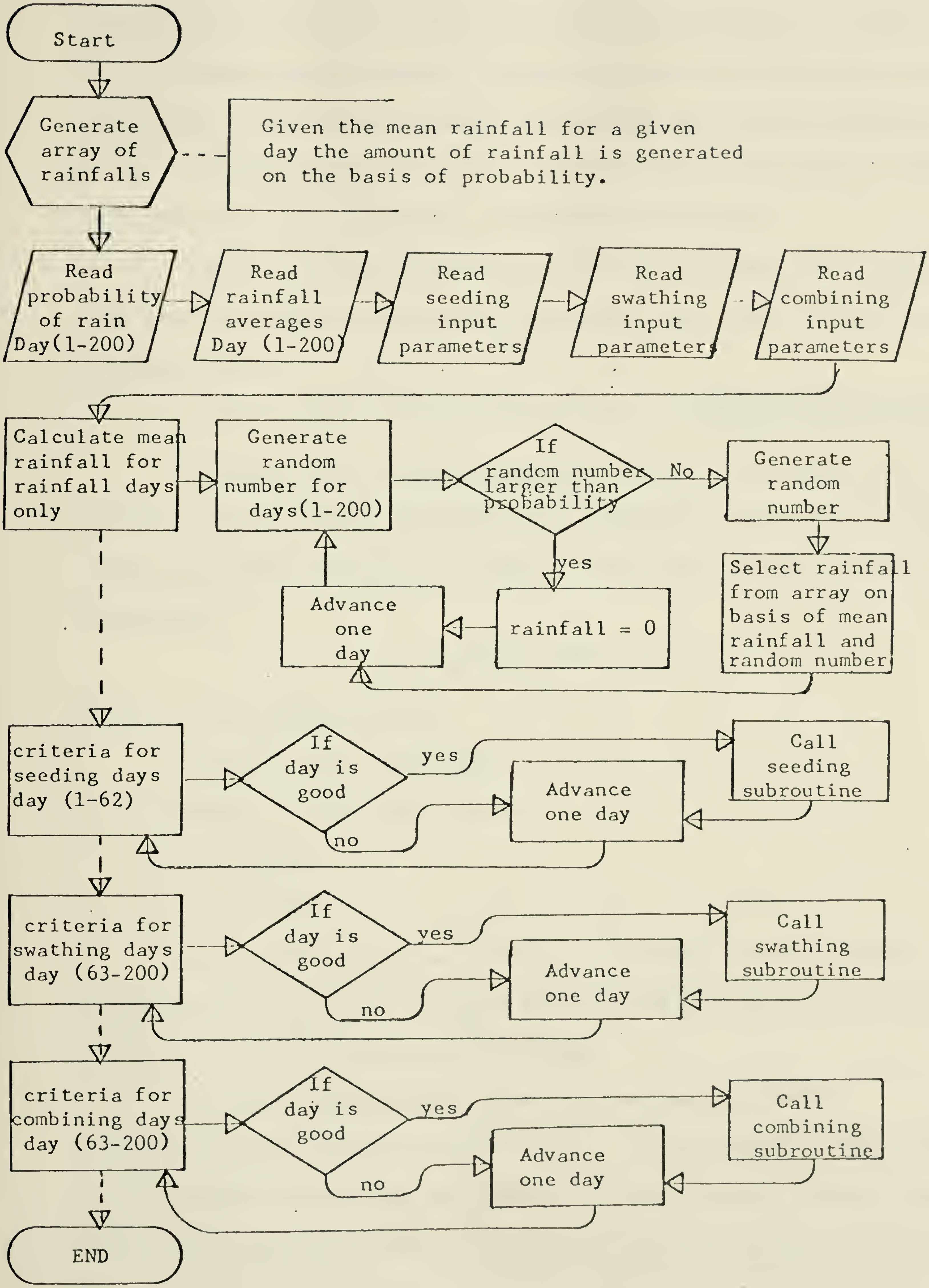

Figure 1. Flowchart of main program.

probability of rain for a given day and the average rainfall for that day (6). A random number generator is used to determine rainfall occurrence on a given day. If the random number is less than the rainfall probability, then it is assumed that rain will occur on that day. The amount of rainfall for that day is determined by the following method:

First, the 99-year average daily rainfall figures for a given date were corrected to include only those years when rainfall occurred. This was done by:

$$\text{average rainfall (for rainfall days)} = \frac{\text{average rainfall (all days)}}{\text{probability of rain}}$$

Secondly, the following exponential function was suggested by the Statistics Department of the University of Manitoba (19) for the purpose of trying to predict the amount of rainfall based on the average rainfall for a given day.

$$P(a < x < b) = e^{-a/m} - e^{-b/m} \quad \text{for } a < b$$

where P is the probability for

x inches of rain, given that

m inches is the average rainfall.

$a = x - 0.005$

$b = x + 0.005.$

A computer program was written to calculate the accumulative probabilities for rainfall averages ranging from 0.01 inch to 0.50 inch and rainfalls of 0.01 inch to 2.00 inches.

The calculated probabilities were compared to rainfall probabilities calculated from weather data. These rainfall probabilities were calculated for average daily rainfalls of 0.15 inch, 0.25 inch, and 0.35 inch. Four days having average daily rainfalls close to these values

were used for the base data. Then the amount of rainfall actually occurring on rainfall days of each year for each day were tabulated in a frequency table where the range of each class was 0.1 inch. Probabilities for each class were calculated by dividing the frequency of the class by the total number of rainfall days observed. Table 1 summarizes these calculations. The resulting accumulated probability was compared to the computed accumulated probability. Figure 2 indicates the comparison for days having an average of 0.25 inch.

This comparison indicated that the computed accumulative probabilities were too low for all three average rainfalls. The following correction factor was established from the above results and incorporated into the computed accumulative probability.

$$\text{corrected probability} = \left[\frac{100 - P}{2.25}\right] + P$$

where P = original computed probability.

With this improvement the program was re-run and the computed and actual accumulative probabilities were again compared for the three average rainfalls as shown in Figure 3.

From these results the author decided that rainfall could be predicted using a random number generator and the modified accumulative probability curves. A two-dimensional array was generated for rainfall with subscripts, average rainfall (0.01 - 0.50) and accumulative probability (1 - 100). Table 2 has been simplified for convenience of display of the generated array. The amount of rain for a given day was selected from the column of the array that contained the rainfall for that day. Specific amounts of rainfall for the day were selected by using a random number generator to select a row of the column. This was done for each day on which rainfall was to occur.

TABLE 1. NUMBER OF RAINFALL OCCURRENCES, PROBABILITY AND ACCUMULATIVE PROBABILITY USING FOUR DAYS WITH SIMILAR AVERAGE RAINFALLS OVER A 99 YEAR PERIOD

Date	Average Rainfall		Amount of Rainfall (inches)																				
			T	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
May 6	0.14																						
May 13	0.16	N	99	23	9	7	2	2	3	0	1												
May 15	0.15	P	.678	.158	.062	.048	.014	.014	0.21	-	.007												
May 28	0.14	AP	.678	.836	.898	.946	.960	.974	.995		1.00												
May 8	0.24																						
June 2	0.25	N	102	32	13	4	7	3	5	0	5	2	2	1	1	0	0	1	0	1	0	1	
June 14	0.25	P	.570	.179	.073	.022	.039	.017	.028	-	.028	.011	.006	.006	.006	-	-	.006	-	.006	-	.006	
June 21	0.25	AP	.570	.749	.822	.844	.883	.900	.928		.956	.967	.973	.979	.985			.991		.007		1.00	
May 14	0.35																						
May 29	0.35	N	105	18	13	9	4	2	4	1	3	5	2	3	0	1	1	1	1	1	1	2	
May 31	0.35	P	.593	.102	.073	.051	.023	.011	.023	.006	.017	.028	.011	.017	-	.006	.006	.006	.006	.006	.006	.011	
June 22	0.35	AP	.593	.695	.768	.819	.842	.853	.876	.882	.899	.927	.938	.955	-	.961	.967	.973	.979	.985	.991	1.00	

T trace amounts of rainfall

N number of rainfall occurrences

P probability

AP accumulative probability

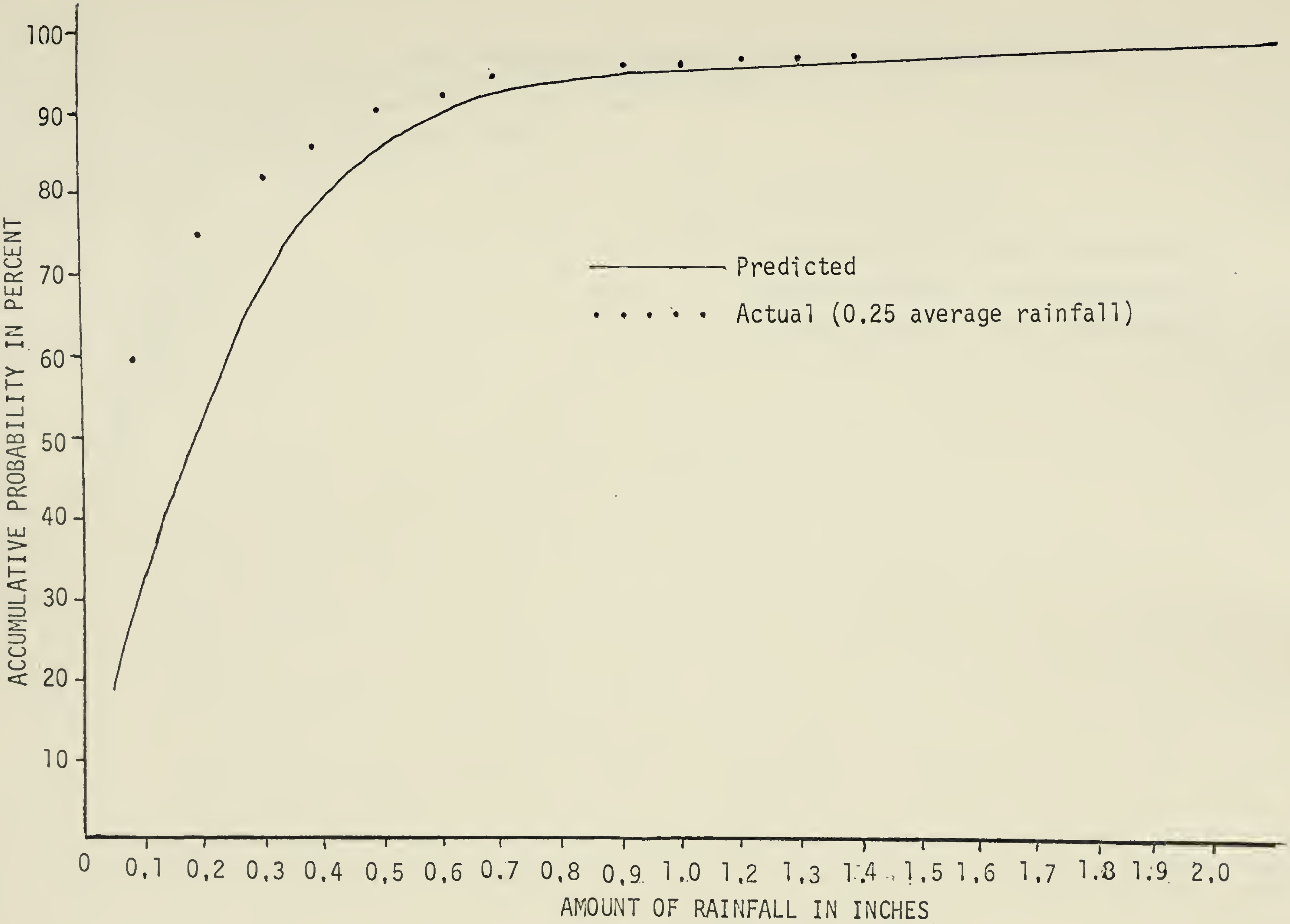

Figure 2. Initial comparison of predicted and actual accumulative rainfall probabilities.

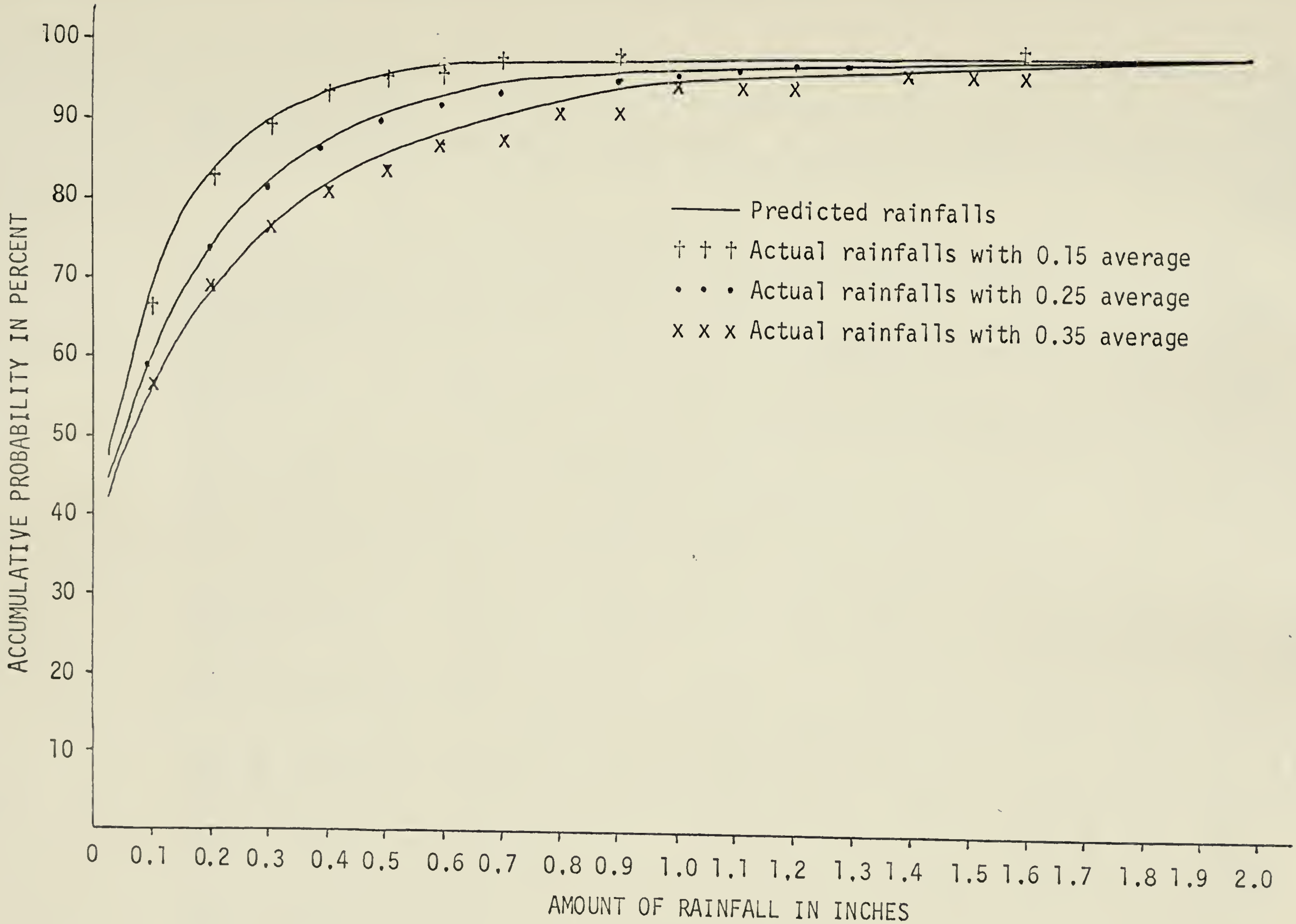

Figure 3. Comparison of predicted and actual accumulative rainfall probabilities.

TABLE 2. COMPUTED RAINFALL AMOUNTS

Accumulative Probability (percent)	Daily Mean Rainfall (inches)									
	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	0.00	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.06
55	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11
60	0.02	0.04	0.06	0.07	0.09	0.11	0.12	0.14	0.15	0.17
65	0.03	0.05	0.08	0.10	0.12	0.15	0.17	0.19	0.21	0.23
70	0.04	0.07	0.10	0.13	0.16	0.19	0.22	0.25	0.28	0.31
75	0.05	0.09	0.13	0.17	0.21	0.25	0.29	0.32	0.36	0.40
80	0.17	0.12	0.17	0.22	0.27	0.32	0.36	0.41	0.46	0.51
85	0.09	0.15	0.21	0.28	0.34	0.40	0.46	0.53	0.59	0.65
90	0.12	0.20	0.28	0.36	0.44	0.52	0.60	0.68	0.76	0.85
95	0.23	0.29	0.40	0.51	0.62	0.71	0.84	0.95	1.06	1.17
100	0.23	0.54	0.87	0.91	1.04	1.21	1.96	2.00	2.00	2.00

4.2 Criteria for Seeding Days.

The prediction of good days and bad days for the seeding program has been based on rainfall. Good days occur as a result of no rainfall or due to loss of moisture when no rainfall occurs after an excess moisture situation. Excess moisture is when the soil is too wet to allow work in the field. Bad days occur as a result of rainfall or of previous excessive moisture.

The model predicts good and bad days for the period May 1 to July 1 for the Red River Valley by the following method: if rainfall for a given day plus previous excess moisture is not greater than 0.05 inch, a good day will result. If rainfall plus previous excess moisture is greater than 0.05 inch but not greater than 0.25 inch, a bad day results but no excess moisture will be added to the following day. If rainfall plus previous excess moisture is greater than 0.25 inch but not greater than 0.5 inch, a bad day results and excess moisture of 0.2 inch will be added to the following day. Thus the following day will be bad even if rainfall does not occur on that day. If rainfall does occur on the following day it will be added to the excess moisture. If rainfall plus previous excess moisture is greater than 0.5 inch but not greater than 1.0 inch, a bad day results and excess moisture equal to 0.45 inch will be added to the following days rainfall. Thus the following two days will be bad even if rainfall does not occur on those days. If rainfall does occur on one or both of the following days, it will be added to the respective excess moisture. If rainfall plus previous excess moisture is greater than 1.0 inch but not greater than 2.0 inches, a bad day results and excess moisture of 0.95 inch is added to the following day. Thus the following three days will be bad even if rainfall does not

occur on those days. If rainfall occurs on one or all three of the following days it will be added to the respective excess moisture. If rainfall plus previous excess moisture is greater than 2.0 inches, a bad day results and excess moisture of 1.95 inches is added to the following days rainfall. Thus the following four days will be bad even if rainfall does not occur on those days. If rainfall occurs on one or all four of the following days, it will be added to the respective excess moisture. Table 3 illustrates a simplified version of the foregoing explanation.

TABLE 3. CRITERIA FOR ESTABLISHING SEEDING DATES AND SWATHING DATES

Condition		Result	
Rainfall (inches)	Excess Moisture on Following Day (inches)	No. of Good Days	No. of Bad Days
0 - 0.05	0.0	1	0
0.06 - 0.25	0.0	0	1
0.26 - 0.50	0.2	0	2
0.51 - 1.00	0.45	0	3
1.01 - 2.00	0.90	0	4
2.01	1.95	0	5

This system was derived as a result of studying the work done by Rutledge (23).

Incorporated into the good and bad day selection was an initial starting date for seeding. The date chosen was May 10 which allowed ten days of weather to be analyzed before actual work could occur. Thus weather conditions previous to the start of seeding will influence the actual starting date. The criteria for establishing seeding dates is shown in Figure 4.

An attempt was made to check the accuracy of the work day predictions. A diary containing field operations over a six year period was

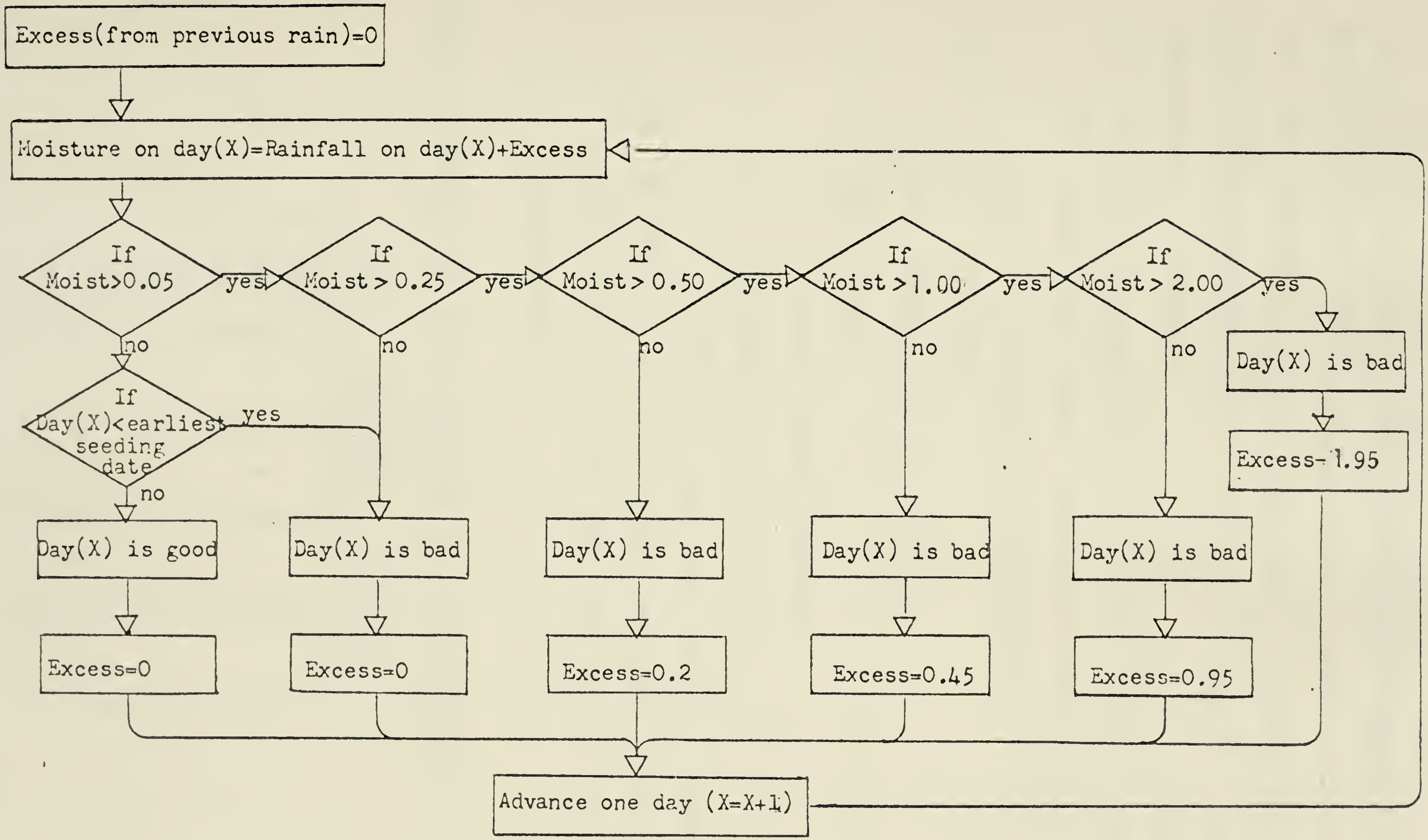

Figure 4. Criteria for establishing seeding and swathing dates.

obtained from the University of Manitoba Research Station at Glenlea. Daily rainfall data was also obtained from the weather station at Glenlea. These daily rainfall readings were read into the computer model and the good and bad days printed out. A comparison was made to the days when field work did, or did not, occur at Glenlea. Table 4 indicates the results. In using this comparison, several factors should be kept in mind:

(1) Glenlea good days were definite but Glenlea bad days occurred because of one or more of the following:

i) rainfall

ii) holidays or long weekends

iii) Sundays

iv) field work was not intended

v) machinery was being repaired

vi) miscellaneous - labor, other work, timeliness.

(2) The Glenlea day of rain can be a work day, that is, if rain occurred late in the day. The model assumes a day of rain is a non-work day.

TABLE 4. COMPUTED AND ACTUAL GOOD DAYS FOR THE PERIOD MAY 7 TO JUNE 30

Year	Computed Good Days	Actual Good Days
1968	31	38
1969	35	34
1970	25	19
1971	38	33
1972	24	29
1973	34	34
Average	32.8	29.5

The criteria as it stands, is accurate from the comparison that can be made on a daily basis; however, the model predicts more work days than actual in total over the months of May and June. This is due to (1) above or the model is slightly generous with good days.

4.3 The Seeding Program

The seeding program is contained in a subroutine of the model which is flowcharted in Figure 5. When a good day occurs the seeding subroutine is called and crop 1 will be seeded for one day provided that the following conditions are met:

(1) initial starting date has been reached.

(2) the last seeding date for crop 1 has not been reached,

(3) all of crop 1 has not been seeded.

If crop 1 is being seeded for the first time, the maturation days for crop 1 are added to the seeding date to establish the earliest swathing date for crop 1. If condition (1) is not met, the model advances to the next day. If condition (2) is not met, the model will:

(a) calculate the penalty for seeding crop 2 instead of crop 1 on the acres remaining to be seeded to crop 1,

(b) increase the acres of crop 2 to be seeded by the amount of crop 1 remaining to be seeded,

(c) seed crop 2 for one day provided that:

(4) The last seeding date for crop 2 has not been reached.

(5) All of crop 2 has not been seeded.

If crop 2 is being seeded for the first time, the maturation days for crop 2 are added to the seeding date to establish the earliest swathing date for crop 2. If condition 3 is not met, the model seeds crop 2 for one day provided that conditions (4) and (5) are true. If condition (4) is not met, the model will:

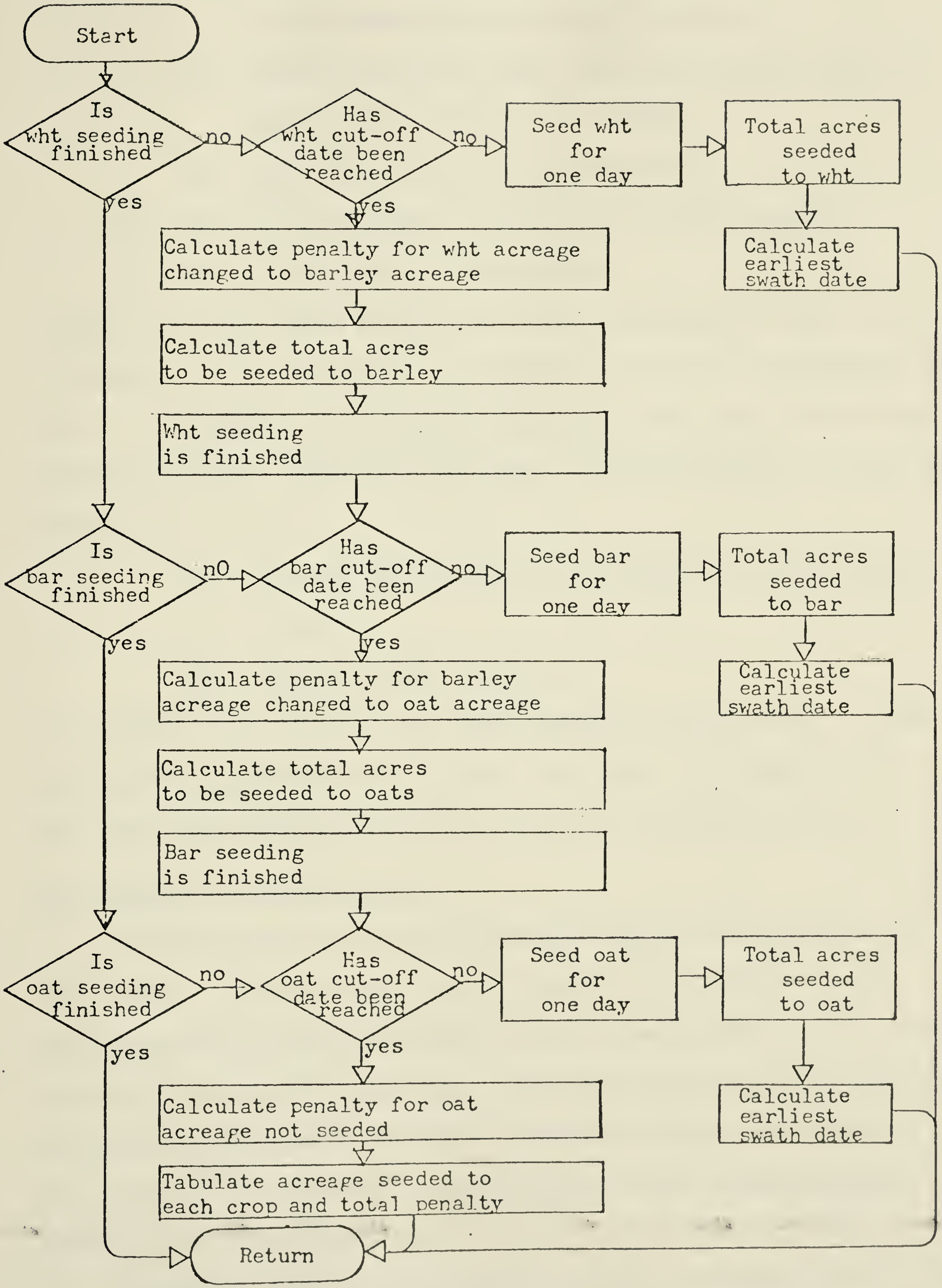

Figure 5. Seeding program subroutine.

(a) calculate the penalty for seeding crop 3 instead of crop 2 on acres remaining to be seeded to crop 2,

(b) increase the crop 3 acres to be seeded by the amount of crop 2 acres remaining to be seeded,

(c) seed crop 3 for one day provided that:

(6) The last seeding date for crop 3 has not been reached.

(7) All of crop 3 has not been seeded.

If crop 3 is being seeded for the first time, the maturation days for crop 3 are added to the seeding date to establish the earliest swathing date for crop 3. If condition (5) is not met, the model seeds crop 3 for one day provided conditions (6) and (7) are true. If condition (6) is not met, the model will:

(a) calculate the penalty on the number of acres not seeded to crop 3,

(b) tabulate seeding results.

If condition (7) is not met, the model tabulates seeding results. Tabulation consists of printing out the date, the total acres seeded to each crop, the total penalty and the total capital and operating costs.

4.4 Criteria for Swathing Days.

Swathing cannot begin until the maturation date for swathing has been reached. The maturation date for swathing is established in the seeding program by adding the number of days to maturation, to the starting date for seeding for each crop. The crop reaching maturity first will be swathed but only until the crop of highest priority reaches maturity. Thus when more than one crop is ready to be cut, the crop with highest priority will be harvested first.

The establishment of good and bad days for swathing is done for the

period July 2 to November 16. Rainfall is used to determine good and bad days for swathing by the same procedure and the same parameter values as used for determining good and bad days for seeding as shown in Table 3.

4.5 The Swathing Program.

The swathing program is contained in a subroutine of the model as shown in Figure 6. When a good day occurs the swathing subroutine is called and crop 1 will be swathed for one day provided that the following conditions are true:

(1) All of crop 1 has not been swathed.

(2) The maturation date for crop 1 has been reached.

If crop 1 is being swathed for the first time, the drying days for crop 1 are added to the swathing date to establish the earliest combining date for crop 1. If condition (1) or (2) is not met the model will swath crop 2 for one day provided that the following conditions are met:

(3) All of crop 2 has not been swathed.

(4) The maturation date for crop 2 has been reached.

If crop 2 is being swathed for the first time, the drying days for crop 1 are added to the swathing date to establish the earliest combining date for crop 2. If condition (3) or (4) is not met the model will swath crop 3 for one day provided that the following conditions are met:

(5) All of crop 3 has not been swathed.

(6) The maturation date for crop 3 has been reached.

(7) Swathing days have not terminated.

If crop 3 is being swathed for the first time, the drying days for crop 3 are added to the swathing date to establish the earliest combining date for crop 3. If condition (5) or (7) is not met the number of acres of each crop swathed and the swathing penalty, if any, are tabulated. If

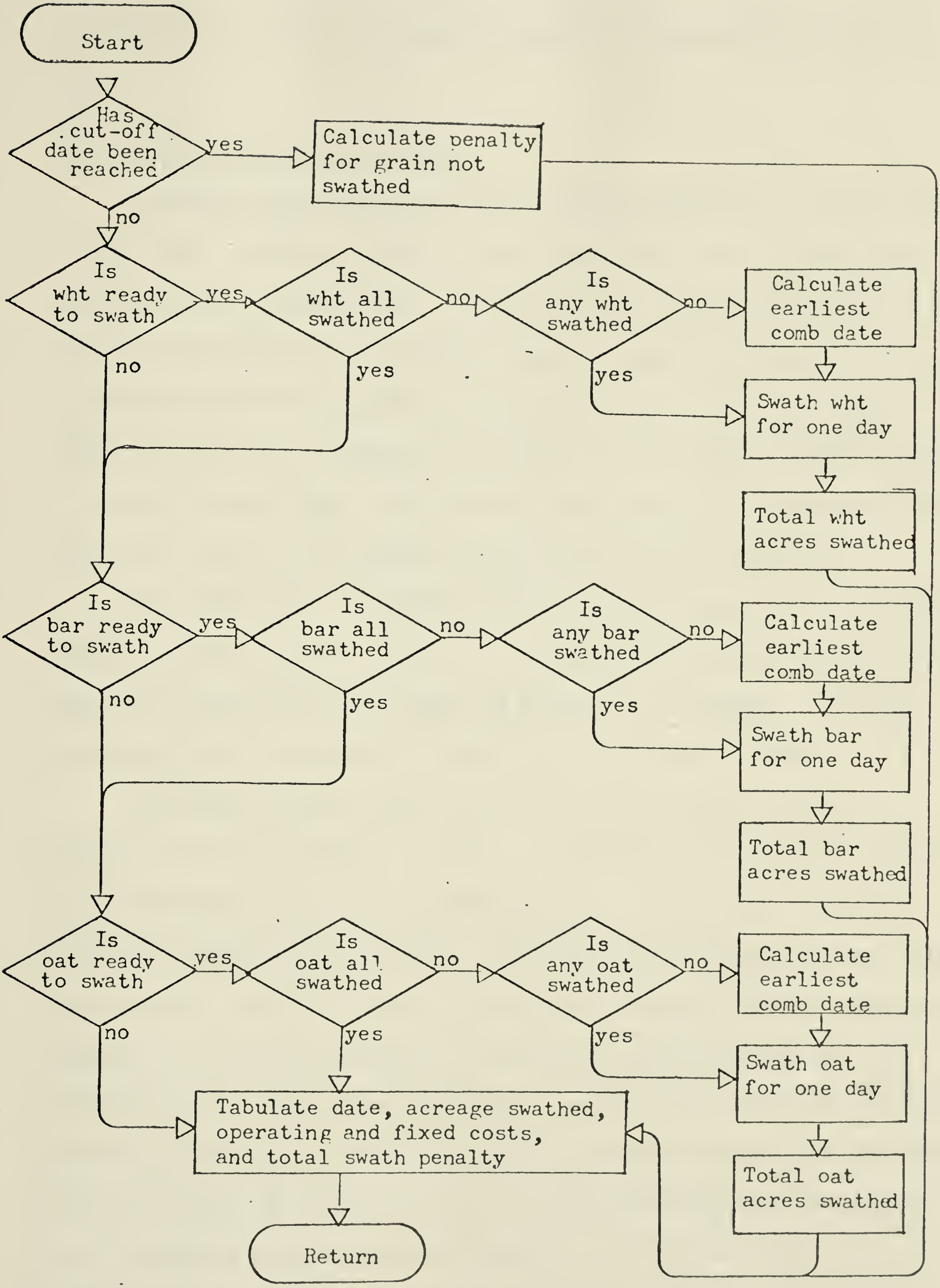

Figure 6. Swathing program subroutine.

condition (6) is not met the model advances one day until (5) or (7) results.

4.6 Criteria for Combining Days.

Combining cannot begin until the crop has dried for a given period of time after swathing. Each crop has a specific number of drying days between swathing and combining. Thus the earliest combining date for each crop is established in the swathing program by adding the appropriate drying days to the initial swathing date for each crop. The crop ready to be combined first will be combined, but only until the crop of highest priority is ready to be combined. Thus when more than one crop is ready to be combined, the crop with the highest priority will be harvested first.

The method used to predict good days and bad days for the combining program has been based on rainfall. The procedure is similar to the procedure for establishing good days and bad days for seeding. The actual parameters were established by Russell (22) as shown in Table 5.

The model predicts good and bad days for the period July 2 to November 16 for the Red River Valley by the following method. If rainfall for a given day plus previous excess moisture is less than or equal to 0.01 inch, a good day will result. If rainfall plus previous excess moisture is greater than 0.01 inch but not greater than 0.15 inch, a bad day results but no excess moisture will be added to the following day. If rainfall plus previous excess moisture is greater than 0.15 inch but not greater than 0.35 inch, a bad day results and excess moisture of 0.06 inch will be added to the following day. Thus the following day will be bad even if rainfall does not occur on that day. If rainfall does occur on the following day it will be added to the excess moisture. If rainfall plus previous excess moisture is greater than 0.35 inch but not greater

than 0.55 inch a bad day results and excess moisture equal to 0.16 inch will be added to the following days rainfall. Thus the following two days will be bad even if rainfall does not occur on those days. If rainfall does occur on one or both of the following days, it will be added to the respective excess moisture. If rainfall plus previous excess moisture is greater than 0.55 inch but not greater than 0.75 inch a bad day results and excess moisture of 0.36 inch will be added to the following day. Thus the following three days will be bad even if rainfall does not occur on those days. If rainfall does occur on one or all three of the following days it will be added to the respective excess moisture. If rainfall plus previous excess moisture is greater than 0.75 inch a bad day results and excess moisture of 0.56 inch is added to the following days rainfall. Thus the following four days will be bad even if rainfall does not occur on those days. If rainfall does occur on one or all four of the following days it will be added to the respective excess moisture. The criteria for establishing combining dates are shown in Figure 7.

The following table illustrates a simplified version of the foregoing explanation.

TABLE 5. CRITERIA FOR ESTABLISHING COMBINING DATES

Condition		Result	
Rainfall (inches)	Excess Moisture on Following Day (inches)	No. of Good Days	No. of Bad Days
0 - 0.1	0.0	1	0
0.02 - 0.15	0.0	0	1
0.16 - 0.35	0.06	0	2
0.36 - 0.55	0.16	0	3
0.56 - 0.75	0.36	0	4
0.76	0.56	0	5

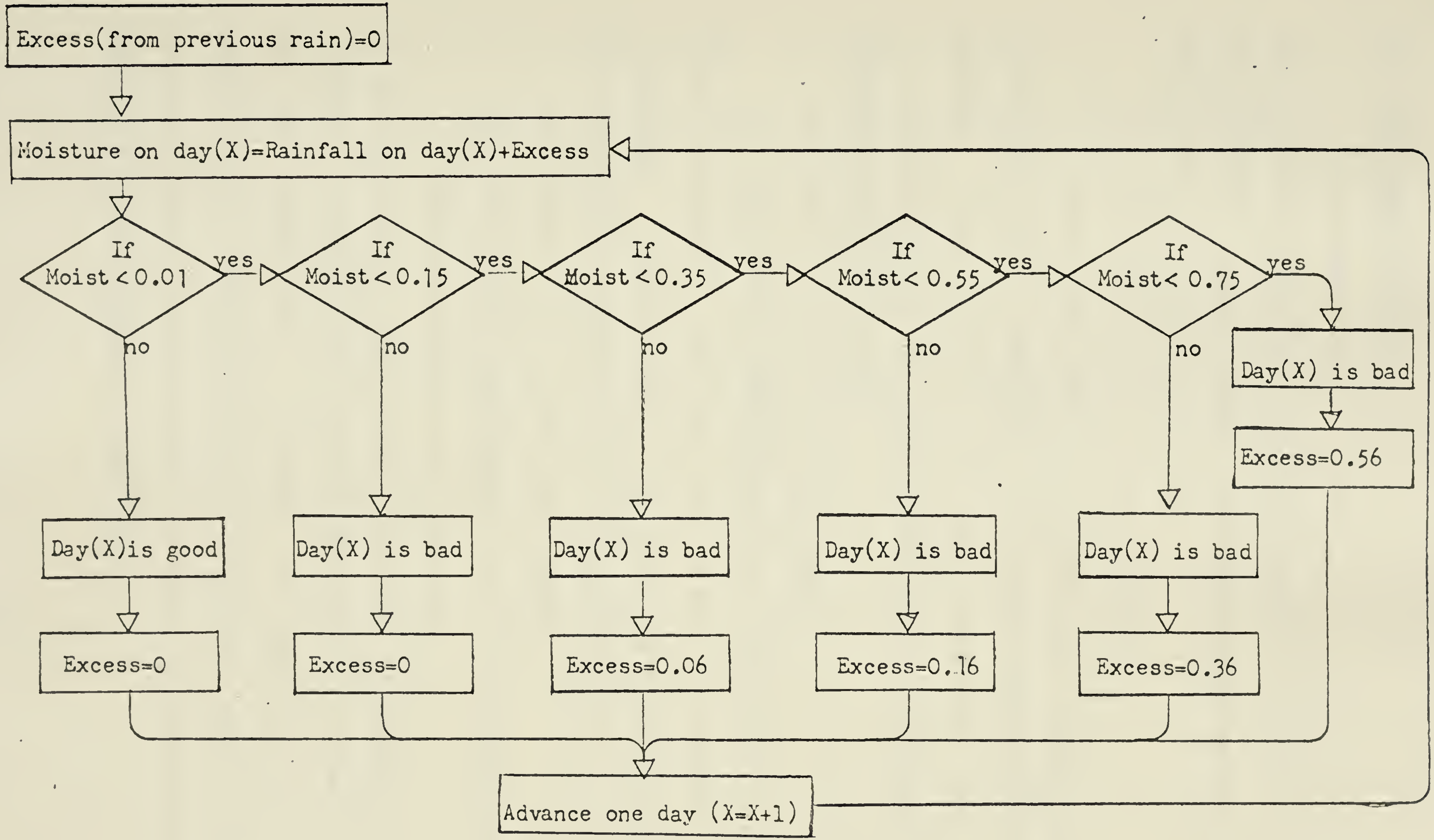

Figure 7. Criteria for establishing combining dates.

4.7 The Combining Program.

The combining program is contained in a subroutine of the model. When a good day occurs the combining subroutine is called and crop 1 will be combined for one day provided that combining days have not terminated and the following conditions are met:

(1) All of crop 1 has not been combined.

(2) The earliest combining date for crop 1 has been reached.

The earliest date for combining crop 1 has been established at the time of swathing. If condition (1) or (2) is not met the model will combine crop 2 for one day provided that combining days have not terminated and the following conditions are met:

(3) All of crop 2 has not been combined.

(4) The earliest combining date for crop 2 has been reached.

The earliest date for combining crop 2 has been established at the time of swathing. If condition (3) or (4) is not met the model will combine crop 3 for one day provided that the following conditions are met:

(5) All of crop 3 has not been combined.

(6) The earliest combining date for crop 3 has been reached.

(7) Combining days have not terminated.

The earliest date for combining crop 3 has been established at the time of swathing. If condition (6) is not met the model will advance one day at a time until condition (6) or (7) results. The number of acres of each crop combined and the combining penalty are tabulated as shown in Figure 8. Combining penalty is based on grade loss due to weathering and on the number of acres not combined for each crop.

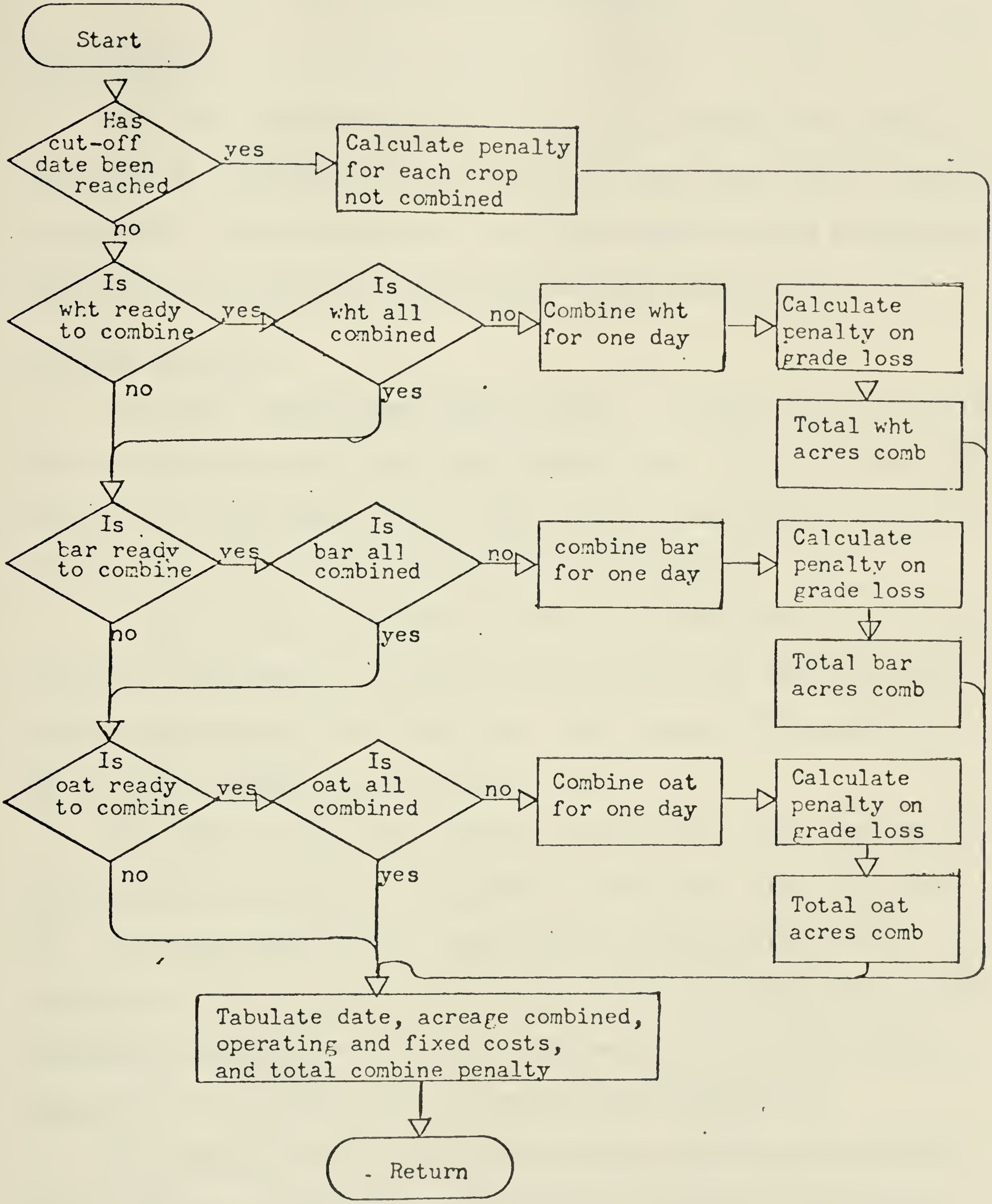

Figure 8. Combining program subroutine.

5. PARAMETERS OF THE MODEL

5.1 Farm Size.

The total number of acres in a farm to be tested by the model is determined by the number of acres in each of three crops used in a rotation as outlined in the next section. The actual farm sizes used in the model were 600 acres, 1200 acres, 1800 acres and 2400 acres.

5.2 Crop Rotation.

The model accepts three types of crops. In general crop 1 is given the highest priority and crop 3 the least priority. That is, crop 1 will be seeded first and crop 3 last. Crop 1 will be harvested as soon as it is ready even if harvest has begun on crop 2 or crop 3.

Crops 1, 2 and 3 chosen for the Red River Valley were wheat, barley and oats, respectively. One third of the farm size was intended to be seeded to each crop for all farm sizes. This, however, is subject to change within the model as explained in 4.3.

The number of days from seeding to swathing for each crop was obtained from the Plant Science Department at the University of Manitoba (11). The maturation days for wheat were 95, barley 87 and oats 90. No attempt was made to vary the length of the maturation dates due to weather influences because the Plant Science Department (11) indicated that the range would only be three days for the Red River Valley area.

The number of days of drying time between swathing and combining for each crop was established by a survey of 125 School of Agriculture students at the University of Manitoba (see Figure 9). The average drying times used were: 7 days for wheat, 5 days for barley and 4 days for oats.

The average yield per acre for the Red River Valley was obtained from the Agricultural Economics Department at the University of Manitoba (14). The yields used were: wheat 30 bushels per acre, barley 45 bushels per acre and oats 60 bushels per acre.

The price per bushel for each crop was based on initial Canadian Wheat Board prices for each grade of grain for the period March 1974 as follows:

TABLE 6. GRAIN PRICES

Crop Value in Dollars per Bushel			
Grade	Wheat	Barley	Oats
1	3.75	2.15	1.06
2	3.68	2.12	1.00
3	3.59	2.07	.96

5.3 Seeding Equipment.

A. Size and Capacity.

The discer seeder is used almost exclusively for seeding in the Red River Valley followed by one or more harrow operations. Four discer widths 15 feet, 18 feet, 24 feet and 30 feet were tested in the model. No provisions were made for entering the harrowing operation into the model. The harrowing operation is separate from the seeding operation and seldom has any bearing on seeding capacity. That is, a second tractor does the harrowing and is assumed to have sufficient capacity to keep up to the seeding operation. Also, the cost of harrowing per acre would be the same for all farm sizes studied in the model. Similarly, truck costs are not analyzed by the model.

The capacity in acres per day of each size of discer was determined

by averaging the results of a survey taken from a class of 125 School of Agriculture students at the University of Manitoba (see Figure 9). The average was 4.85 acres per foot of width per day. Assuming a 10-hour day and 5.5 miles per hour speed of operation, the efficiency of the seeding machine becomes 72.75 percent when solving for efficiency using the following:

$$C = \frac{S \times W \times E}{825}$$

where C = capacity in acres per hour

S = speed in miles per hour

W = width in feet

E = efficiency in percent

From the authors' own farming operation, an average of 9 hours is required to seed 80 acres with an 18 foot discer at 5.5 miles per hour. The efficiency on the basis of the above formula is 74 percent. Principles and Practices of Commercial Farming (20) suggests 72.5 percent efficiency for the seeding operation. A United Grain Growers' publication (9) in January 1974 indicates an actual work rate for a 15 foot discer of 7.2 acres per hour. At the rate of 4.85 acres per foot of width per day used in the model, the rate becomes 7.27 acres per hour based on a 10-hour day. Because of these close similarities, the rate of 4.85 acres per foot of width per day was assumed to be accurate. The daily capacities of each of the machines tested in the model are as follows:

TABLE 7. SEEDING MACHINE CAPACITY

Seeding Machine Width (feet)	Capacity (acres per day)
15	72.7
18	87.3
24	116.4
30	145.5

B. Power Requirements.

Tractor size was determined for each discer size by a method outlined in Principles and Practices of Commercial Farming (20).

$$HP = \frac{\text{Draft} \times \text{MPH}}{375}$$

where HP = total draft in pounds

MPH = speed in miles per hour

The suggested draft per foot of width for the discer seeder is 150 to 225 pounds for all soils. The average, 187.5 pounds per foot of width, was used. A speed of 5.5 miles per hour was used in determining the power requirements. The suggested drawbar efficiency for heavy soils is 75 percent of maximum drawbar horsepower. Also, maximum drawbar horsepower is 80 percent of maximum power-take-off horsepower. Using these parameters the following tractor sizes are required for each discer size:

TABLE 8. HORSEPOWER REQUIREMENTS FOR SEEDING MACHINES

Discer Width (feet)	Tractor PTO Horsepower
15	68.8
18	82.5
24	110.5
30	137.5

C. Costs.

The method used for calculating fixed and operating costs for the seeding equipment was based on a method outlined in "The Grain Grower" (24) whose source was Manitoba, Saskatchewan and Alberta Departments of Agriculture. The fixed costs were calculated on an annual basis and the operating costs on an hourly basis from Table 9.

TABLE 9. FARM MACHINERY LIFETIME AND REPAIR RATES

Machine	Years Until Obsolete	Normal Annual Use In Hours	Expected Life In Hours	Repair Rate as % of Original Purchase Price
Tractor	13	600	7800	40
Combine	12	150	1800	65
Swather	15	100	1500	35
Discer	15	120	1800	30

Since the tractor and discer are used for other parts of the farm operation and this study is concentrated only on the costs of seeding and harvesting, the depreciation cost per year was calculated on an hourly basis. That is, depreciation was calculated on the actual hours of use during seeding. The fixed and operating costs are then calculated as follows:

(1) Fixed costs

a. Depreciation per year =

$$\frac{\text{90\% of purchase value x annual use (hours)}}{\text{expected life in hours}}$$

b. Interest on investment =

$$\text{interest rate x } \frac{\text{purchase value + 10\% purchase value}}{2}$$

(2) Operating costs

a. Fuel costs per hour = gallons per hour x price per gallon

b. Labour per hour

c. Repair cost per hour = $\frac{\text{purchase price x repair rate}}{\text{expected life in hours}}$

The purchase price for diesel tractors and discers for the model were determined by contacting four farm equipment dealers in the Winnipeg area in January 1974 and obtaining the list price of each tractor and discer size. The average of the four prices for each piece of equipment is

shown in the following table.

TABLE 10. LIST PRICES OF SEEDING EQUIPMENT

Tractor PTO-HP	Average List Price	Discer Width	Average List Price
68.8	$ 9450	15	$ 3373
82.5	11745	18	3723
110.0	15876	24**	6590
137.5	17550*	30**	7036

*four-wheel drive tractor
**duplex discer

The fuel consumption for each tractor was determined by obtaining an average fuel consumption in gallons per horsepower (PTO) per hour from six Nebraska Tests (18) for diesel tractors in the hundred horsepower range. The category selected to represent field conditions was "75% pull at Maximum Power" under "Varying Drawbar Power and Fuel Consumption with Ballast". The average consumption was 0.0465 Imperial gallons per horsepower hour. The farm price for diesel fuel in January 1974 was 27.5 cents per gallon in the Winnipeg area.

A labour cost of 3 dollars per hour was charged for the seeding operation. This is the average labour charge suggested by "Rental and Custom Charges for Farm Machinery" (21).

Depreciation for each tractor and discer combination was calculated on an hourly basis related to farm size. For example, the depreciation for the smallest seeding size on a 600-acre farm size calculated as follows:

$$\text{Depreciation per year} = \frac{90\% \text{ of purchase value x annual use (hours)}}{\text{expected life in hours}}$$

Tractor purchase value = $9450 (from Table 10)

Tractor annual use = 82.5 hr = 600 ac ÷ 7.27 ac/hr (from Table 7)

Tractor expected life = 7800 hr (from Table 9)

Thus,

$$\text{Tractor depreciation per year} = \frac{.9(9450) \times 82.5}{7800} = 89.96 \text{ dollars}$$

Discer purchase value = \$3373 (from Table 10)

Discer annual use = 82.5 hr = 600 ac ÷ 7.27 ac/hr (from Table 7)

Discer expected life = 1800 hr (from Table 9)

Thus,

$$\text{Discer depreciation per year} = \frac{.9(3373) \times 82.5}{1800} = 139.14 \text{ dollars}$$

Total annual depreciation for the seeding equipment = 229.10 dollars

Interest costs for each tractor and discer combination was calculated on an annual basis regardless of farm size. An interest rate of 8.5 percent was used as suggested by "Rental and Custom Charges for Farm Machinery" (21). Thus, the annual interest cost for the smallest seeding size was calculated as follows:

Interest on investment =

$$\text{interest rate} \times \frac{\text{purchase value} + 10\% \text{ purchase value}}{2}$$

Interest rate = 0.085

Purchase value = (9450 + 3373) = 12823 dollars (from Table 10)

Total annual interest on seeding equipment =

$$0.085 \times \frac{(12823 + 1282.30)}{2} = 599.48 \text{ dollars}$$

Repair costs were calculated on an hourly basis for each equipment size. For example, the repair cost for the smallest seeding equipment size was calculated as follows:

$$\text{Repair cost per hr} = \frac{\text{purchase price} \times \text{repair rate}}{\text{expected life in hours}}$$

Tractor purchase price = \$9450 (from Table 10)

Tractor repair rate = 40% (from Table 9)

Tractor expected life in hours = 7800 (Table 9)

Tractor repair cost per hour = $\frac{9450 \times .40}{7800}$ = \$0.4846 per hour

Discer purchase price = \$3373 (from Table 10)

Discer repair rate = 30% (from Table 9)

Discer expected life in hours = 1800 (from Table 9)

Discer repair cost per hour = $\frac{3373 \times .30}{1800}$ = \$0.563 per hour

The sum of the operating costs per hour were then multiplied by the annual hours of use to determine the annual operating cost for each farm size and seeding equipment size. The annual hours of use is a function of seeding equipment capacity and farm size. The total annual cost for the seeding equipment is the sum of the annual operating and fixed costs as shown in Table 11.

5.4 Seeding Penalties

The last dates for seeding were established for the Red River Valley in conjunction with the Plant Science Department at the University of Manitoba (11). The last dates are based on the days to maturity for each crop and the average date on which the first frost occurs (6). The last dates for seeding used in the model were: wheat - June 10, barley - June 18, oats - June 18.

Penalties for not getting a crop or part of a crop seeded are calculated within the model on the basis of average yield and price per bushel. One crop will be substituted for another crop if possible. For example, if the last seeding date for wheat is reached before wheat seeding is finished, barley will be seeded in place of wheat. The penalty involved will be calculated on the difference between gross returns per

TABLE 11. SEEDING EQUIPMENT COSTS

Capacity and Size	Farm Size (acres)	Seeding Time (hours)	Discer Deprec. ($/yr)	Tractor Deprec. ($/yr)	Discer Repair ($/yr)	Tractor Repair ($/yr)	Interest ($/yr)	Fuel ($/yr)	Labour ($/yr)	Total Cost ($/yr)	Total Cost ($/ac)
7.27(ac/hr) Discer (15 ft) Tractor (67.5 pto-HP)	600	82.5	138.85	89.84	46.45	39.98	599.48	71.24	247.50	1233.34	2.06
	1200	165.0	277.70	179.69	92.90	79.96	599.48	142.48	495.00	1867.21	1.56
	1800	247.6	416.71	269.63	139.40	119.99	599.48	213.80	742.80	2501.81	1.39
	2400	330.1	555.39	359.48	185.79	159.92	599.48	284.96	990.00	3135.02	1.31
8.73(ac/hr) Discer (18 ft) Tractor (81.0 pto-HP)	600	68.7	127.99	93.36	42.73	41.39	723.13	73.68	206.10	1308.38	2.18
	1200	137.5	256.16	186.86	85.53	82.84	723.13	147.47	412.50	1894.49	1.58
	1800	206.2	384.15	280.23	128.26	124.24	723.13	221.13	618.60	2479.76	1.37
	2400	274.9	512.14	373.59	170.99	165.63	723.13	294.83	824.70	3065.01	1.28
11.64(ac/hr) Discer (24 ft) Tractor (108.0 pto-HP)	600	51.6	169.97	94.74	56.71	41.98	965.29	71.17	154.65	1554.51	2.59
	1200	103.1	339.61	189.29	113.40	83.96	965.29	142.32	309.27	2143.14	1.79
	1800	154.6	509.25	283.85	170.10	125.94	965.29	213.48	463.92	2731.83	1.52
	2400	206.2	679.22	378.58	226.81	167.92	965.29	284.65	618.57	3321.04	1.38
14.55(ac/hr) Discer (30 ft) Tractor (135.0 pto-HP)	600	41.2	144.98	83.43	48.66	37.13	1149.40	68.05	123.72	1655.37	2.76
	1200	82.5	290.32	167.06	97.31	74.25	1149.40	136.08	247.41	2161.83	1.80
	1800	123.7	435.30	250.49	145.98	111.38	1149.40	204.12	371.13	2667.80	1.48
	2400	165.0	580.64	334.13	194.64	148.51	1149.40	272.16	494.85	3174.33	1.32

acre for the two crops for the number of acres involved in the substitution. Similarly oats may be substituted for barley with corresponding penalty. When the latest seeding dates have been reached the penalty is calculated on the gross return for the number of acres of each crop left to be seeded. The gross return is the price per bushel multiplied by the average bushels per acre for each crop. That is,

$$P_X = f\ (Y_X \times PR_X \times UA_X - Y_S \times P_S \times A_S)$$

where P_X = penalty for crop x

Y_X = average yield in bushels per acre for crop x

PR_X = price per bushel for crop x

UA_X = number of unseeded acres of crop x

Y_S = average yield in bushels per acre for substituted crop

P_S = price per bushel for substituted crop

A_S = number of acres of substituted crop

The total penalty for seeding is the sum of all penalties described above. The yields and prices for each crop have been described in section 5.2.

5.5 Harvesting Equipment

A. Size and Capacity.

Harvest equipment used in the model consists of a self-propelled swather and a self-propelled combine. Three harvest equipment sizes were tested in the model: a 15-foot swather and corresponding combine, a 20-foot swather and corresponding combine and a 30-foot swather and corresponding combine. Swather and corresponding combine size was established in a class survey of 125 School of Agriculture students at the University of Manitoba (Figure 9). Table 12 illustrates swather size and the criteria for corresponding combine size.

CROP: ____________

Type: ________ No. Acres: ________

Average yield: ________

Date to Start Seeding

Earliest ________ Average ________ Latest ________ Final cut-off date for this crop ________

Time required to seed this crop ______ days

Time required to harvest ___ days

	MACHINE REQUIREMENTS											TRACTOR REQUIREMENTS			
Operation No.	Type of Machine	Width	Operating Speed	Reload time Seed	Reload time Fert.	Seed Capacity	Fert. Capacity	Seeding Rate	Fert. Rate	Capital Cost	Operating Cost	Type	Size PTO HP	Capital Cost	Operating Cost
Operation 1															
Operation 2															
Operation 3															
Operation 4															
Operation 5															
Harvesting Operation	Type of Machine	Width	Operating Speed	Combines only: cyl. width	cleaning area	straw walker length	body width	acres/day	make & model	Capital Cost	Operating Cost				
1															
2															
3															

With no rainfall and average drying days what length of time is required after swathing to combine this crop dry. ____________days.

HARVEST CROP LOSSES

RAINFALL		COMBING DELAY(day)	LOSS IN GRADE	LOSS IN $/ACRE
1 day	0.5"			
	1.0"			
2 days				
3 days				
4 days				
5 days				

Figure 9. Farm and classroom survey form.

TABLE 12. SWATHER AND CORRESPONDING COMBINE SIZES

Harvest Equipment Size	Swather Size Width of Cut (feet)	Combine Size	
		Cylinder Width (inches)	Separating Area (square inches)
small	15	36 - 40	7000 - 9000
medium	20	40 - 50	9000 - 13000
large	30	50 - 60	13000+

Swather capacities were also established from the above classroom survey. The capacities used in the model for all crops are shown in Table 13. Assuming a speed of 5.5 miles per hour and a 10 hour day, the swathing efficiency is 75 percent.

Combine capacities were also established from the above classroom survey. The capacities used in the model for all crops were:

TABLE 13. COMBINE CAPACITIES

Harvest Equipment Size	Swather Size (feet)	Swather Capacity (ac/day)	Combine Capacity (ac/day)
small	15	75	40
medium	20	100	60
large	30	150	80

A formula developed by MacHardy (16) was used to determine theoretical combine capacities and subsequently the daily efficiency based on the above capacities.

$$Y = 3\left[\frac{W}{192} + \frac{B^{3/2} \times L}{38600} + \frac{S}{7400}\right]$$

where Y = field capacity in long tons/hr

W = cylinder width in inches

B = body width in inches

L = straw walker length in inches

S = combined chaffer and sieve area in square inches

Using the above formula Campbell (2) calculated the following capacities.

TABLE 14. THRESHING CAPACITIES

Combine Size	Make and Model	Short ton/hr*	lb/min**	Grain bu/hr***
small	JD 55, MF 82, IHC 303	4.0	135	135
medium	JD 360, MF 410, IHC 503	5.8	195	195
large	JD 730, NH 995	7.9	260	260

*1.1 short ton = long ton
**straw and chaff
***for grain/straw ratio = 1 and 60 lb = 1 bushel

The grain-straw ratio of 1 for wheat was established in conjunction with the Plant Science Department at the University of Manitoba (11). Assuming a 10-hour day for combining and an average wheat crop of 30 bushels per acre, the theoretical capacities and subsequent efficiencies are shown in the following table.

TABLE 15. COMBINE EFFICIENCY

Combine Size	Theoretical Capacity	Actual Capacity	Efficiency
small	45 acres/day	40 acres/day	88%
medium	65 acres/day	60 acres/day	92%
large	87 acres/day	80 acres/day	92%

B. Costs.

The method used for calculating fixed and operating costs for the harvesting equipment was based on a method outlined in Section 5.3, C. The purchase prices for swathers and combines were arrived at by contacting four dealers in the Winnipeg area in January 1974 and obtaining the

list price of each swather and combine size. The average of the four prices for each size of equipment is shown in the following table.

TABLE 16. AVERAGE LIST PRICE FOR SELF-PROPELLED SWATHERS AND COMBINES

Size	Windrow Width (feet)	Swather ($)	Combine ($)
small	15	4725	15000
medium	20	5200	22000
large	30	8500	27000

Several farmers owning self-propelled swathers were contacted to establish an average rate of fuel consumption for swathing. The rate, regardless of size, was 0.2 gallons per acre. The price for farm gasoline in January 1974 was 30 cents per gallon. This constitutes a fuel cost of 6 cents per acre. The cost per hour is simply the swather capacity in acres per hour multiplied by 6 cents per acre. Fuel costs for swathing are shown in Table 17.

The average fuel consumption for combining was established on the basis of the average horsepower for each size of combine. An average gasoline consumption of 0.55 pounds per horsepower hour was established from several "Nebraska Tests" for gasoline tractors in the 100-horsepower range. An assumption was made that the combine would be loaded to 80 percent of engine capacity. The fuel cost per hour for combining was then calculated with a gasoline cost of 30 cents per gallon as above. Fuel costs for combining are shown in Table 18.

A labour charge of 3 dollars per hour was charged for the swathing and combining operations. This is the average wage suggested by "Rental and Custom Charges for Farm Machinery" (21).

Depreciation for each swather and combine combination was calculated

TABLE 17. SWATHING EQUIPMENT COSTS

Swather Width (feet)	Swather Capacity (ac/hr)	Farm Size (acres)	Swathing Time (hr)	Swather Deprec. ($/yr)	Swather Repair ($/yr)	Interest ($/yr)	Fuel ($/yr)	Labour ($/yr)	Total Cost ($/yr)	Total Cost ($/ac)
15	7.5	600	80	283.50	88.20	220.89	36	240	868.59	1.45
		1200	160	283.50	176.40	220.89	72	480	1232.79	1.03
		1800	240	283.50	264.60	220.89	108	720	1596.99	.89
		2400	320	283.50	352.80	220.89	144	960	1961.19	.82
20	10.0	600	60	312.00	72.80	243.10	36	180	843.90	1.41
		1200	120	312.00	145.60	243.10	72	360	1132.70	.94
		1800	180	312.00	218.40	243.10	108	540	1421.50	.79
		2400	240	312.00	291.20	243.10	144	720	1710.30	.71
30	15.0	600	0	510.00	79.33	397.38	36	120	1142.71	1.91
		1200	80	510.00	158.67	397.38	72	240	1378.05	1.15
		1800	120	510.00	238.00	397.38	108	360	1613.38	.90
		2400	160	510.00	317.33	397.38	144	480	1848.71	.77

TABLE 18. COMBINING EQUIPMENT COSTS

Windrow Width (feet)	Combine Capacity (ac/hr)	Farm Size (acres)	Combine Time (hr/yr)	Combine Deprec. ($/yr)	Combine Repair ($/yr)	Interest ($/yr)	Fuel ($/yr)	Labour ($/yr)	Total Cost ($/yr)	Total Cost ($/ac)
15	4	600	150	1125.00	812.50	701.25	240.75	450	3329.50	5.55
		1200	300	1125.00	1625.00	701.25	481.50	900	4832.75	4.03
		1800	450	1125.00	2437.50	701.25	722.25	1350	6336.00	3.52
		2400	600	1125.00	3250.00	701.25	963.00	1800	7839.25	3.27
20	6	600	100	1650.00	794.44	1028.50	204.00	300	3976.94	6.63
		1200	200	1650.00	1588.89	1028.50	408.00	600	5275.39	4.40
		1800	300	1650.00	2383.33	1028.50	612.00	900	6573.83	3.65
		2400	400	1650.00	3177.78	1028.50	816.00	1200	7872.28	3.28
30	8	600	75	2025.00	731.25	1243.98	186.75	225	4411.98	7.35
		1200	150	2025.00	1462.50	1243.98	373.50	450	5554.98	4.63
		1800	225	2025.00	2193.75	1243.98	560.25	675	6697.98	3.72
		2400	300	2025.00	2925.00	1243.98	747.00	900	7840.98	3.27

on a yearly basis. For example, the depreciation for the smallest harvest equipment size was calculated as follows:

$$\text{Depreciation per year} = \frac{\text{90\% of purchase value}}{\text{expected life in years}}$$

Swather purchase value = 4725 dollars (from Table 16)

Swather expected life = 15 years (from Table 9)

Thus,

$$\text{Swather depreciation} = \frac{.9(4725)}{15} = 283.50 \text{ dollars}$$

Combine purchase value = 15000 dollars (from Table 16)

Combine expected life = 12 years (from Table 9)

Thus,

$$\text{Combine depreciation} = \frac{.9(15000)}{12} = 1125 \text{ dollars}$$

Total annual depreciation for harvesting equipment = 1408.50 dollars

Interest costs for the harvesting equipment were calculated on an annual basis using an interest rate of 8.5 percent as suggested by "Rental and Custom Charges for Farm Machinery" (21). Thus, the annual interest cost for the smallest harvesting equipment was calculated as follows:

Interest on investment =

$$\text{interest rate} \times \frac{\text{purchase value + 10\% purchase value}}{2}$$

interest rate = 0.085

Purchase value = (4725 + 15000) = 19725 dollars (from Table 16)

$$\text{Total annual interest} = 0.085 \times \frac{(19725 + 1972.50)}{2} = 922.14 \text{ dollars}$$

Repair costs were calculated on an hourly basis. For example, the smallest harvest equipment rapair rate was calculated as follows:

Swather cost = 4725 dollars (from Table 16)

Swather life in hours = 1500 hours (from Table 9)

Swather repair rate = 35% (from Table 9)

Swather repair cost per hour = $\frac{4725 \times 0.35}{1500}$ = 1.10 dollars

Combine cost = 15000 dollars (from Table 16)

Combine life in hours = 1800 hours (from Table 9)

Combine repair rate = 65% (from Table 9)

Combine repair cost per hour = $\frac{15000 \times 0.65}{1800}$ = 5.42 dollars

Total harvest equipment repair rate = 6.52 dollars per hour

This repair cost was treated as an operating cost.

The sum of the operating costs per hour were multiplied by the annual hours of use to determine the annual operating cost for each farm size and harvesting equipment size. The annual hours of use is a function of harvesting equipment capacity and farm size. The total annual cost for the harvesting equipment is the sum of the annual operating and fixed costs as shown in Table 19.

5.6 Harvest Penalties

A. Grade Loss.

A counter built into the computer model totals the number of bad days after crop maturation. The grade is established on a daily basis determined by the total number of bad days after maturation as outlined by Russell (22). The Canadian Wheat Board grading system has changed since Russell's work so changes were made as shown in Table 20. Based on Russell's (22) work, the grading was done as follows. If the total number of bad days after the maturation date for crop 1 is:

(1) less than three days, the grade will be 1

(2) three days the grade will be 2

(3) more than three days, the grade will be:

(a) 2 if no rain occurs on the fourth day

TABLE 19. HARVESTING EQUIPMENT COSTS

Swather Width (feet)	Swather Capacity (ac/hr)	Combine Capacity (ac/hr)	Farm Size (acres)	Swather Cost ($/yr)	Swather Cost ($/ac)	Combine Cost ($/yr)	Combine Cost ($/ac)	Total Cost ($/yr)	Total Cost ($/ac)
15	7.5	4	600	868.59	1.45	3329.50	5.55	4198.09	7.00
			1200	1232.79	1.03	4832.75	4.03	6065.54	5.06
			1800	1596.99	0.89	6336.00	3.52	7932.99	4.41
			2400	1961.19	0.82	7839.25	3.27	9800.44	4.09
20	10.0	6	600	843.90	1.41	3976.94	6.63	4820.84	8.04
			1200	1132.70	0.94	5275.39	4.40	6408.09	5.34
			1800	1421.50	0.79	6573.83	3.65	7995.33	4.44
			2400	1710.30	0.71	7872.28	3.28	9582.58	3.99
30	15.0	8	600	1142.71	1.91	4411.98	7.35	5554.69	9.26
			1200	1378.05	1.15	5554.98	4.63	6933.03	5.78
			1800	1613.38	0.90	6697.98	3.72	8311.36	4.62
			2400	1848.71	0.77	7840.98	3.27	9689.69	4.04

(b) 3 if rain occurs on the fourth day or if there are more than four bad days.

This procedure has been flowcharted in Figure 10. The grade of grain is established for wheat in the model and the same grading system is used for barley and oats.

TABLE 20. REVISED GRADES OF GRAIN

Old Grade	New Grade
1	1
2	1
3	2
4	2
5	3
6	3
7	3

B. Latest Dates for Harvesting.

The last date for swathing and combining was set at November 16. The average date for freeze-up is November 16 for the Winnipeg area (6). The chances of harvesting after this date are improbable because of the cold temperature and short days.

C. Value of Crop not Harvested.

The penalty for not getting a crop swathed is calculated within the model on the number of acres not swathed and the total value of that crop per acre. That is, if a crop is not swathed before winter, there is no recovery the following year.

On each day of combining, penalties are calculated according to the grade loss and the subsequent price loss per bushel for the total number of bushels threshed on that day for each specific crop. The

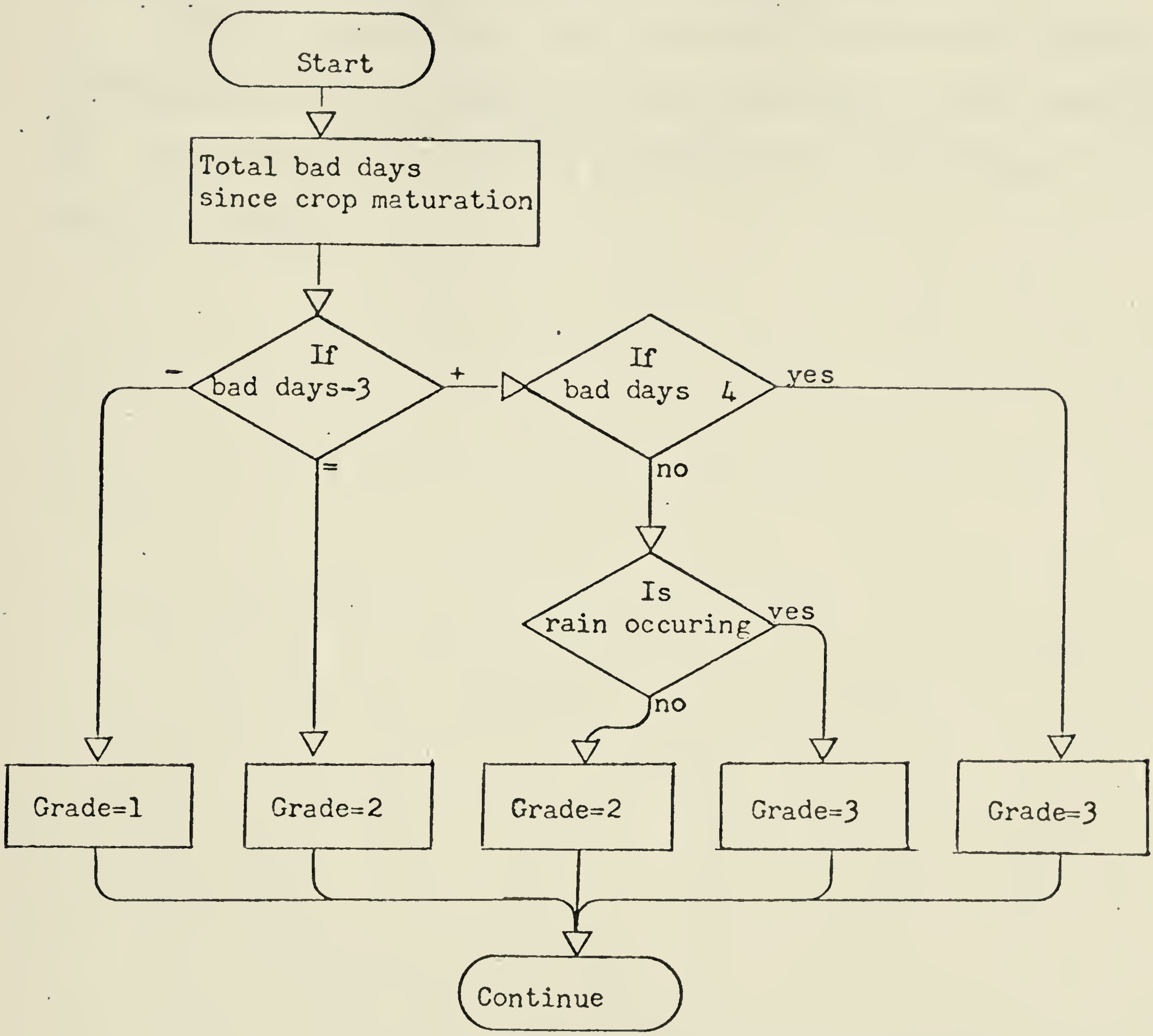

Figure 10. Criteria for establishing the grade of grain.

penalty for not getting a swathed crop combined before the last combining date was established at half the value of the crop. That is, 50 percent recovery could be made by combining the following spring.

Swathing penalties are totalled on the final date for combining. Combining penalties are summed on a day to day basis for each combining day. Both swathing and combining penalties are accumulated over the 100 years of farming.

6. RESULTS AND DISCUSSION

The 100 year annual average machine costs and penalty costs for all combinations of farm sizes, seeding equipment sizes and harvest equipment sizes are summarized in Table 21.

The model indicates that the actual cost of owning any one of the four seeding equipment sizes for a particular farm size does not vary greatly. That is, all four sizes cost about the same on a per acre basis. In terms of penalty costs there is a risk of under sizing the seeding equipment. The minimum seeding equipment sizes and capacities for the acreages studied on the basis of machinery costs and penalties are as follows:

TABLE 22. MINIMUM SEEDING EQUIPMENT SIZES

Farm Size (acres)	Width of Seeding Machine (feet)	Capacity (acres per hour)
600	15	7.27
1200	18	8.73
1800	24*	11.64
2400	30**	14.55

*Average penalty of $182 per year due to insufficient capacity.
**Average penalty of $323 per year due to insufficient capacity.

The annual costs of the three harvesting equipment sizes are very similar when depreciation is calculated on the hours of use per year based on equipment life-time in hours. However, when depreciation is calculated yearly (based on the life-time in years) it becomes less economical to own a large harvesting system on a small acreage because the annual hours of use are very small making the depreciation cost per acre very high. As the acreage becomes larger the difference in the cost of owning a small

TABLE 21. AVERAGE YEARLY EQUIPMENT AND PENALTY COSTS BASED ON ONE HUNDRED YEARS OF SIMULATED FARMING

Program No.	Seeding Width (feet)	Harvest Width (feet)	Farm Size (acre)	Seeding Cost ($/yr)	Harvest Cost ($/yr)	Seeding Penalty ($/yr)	Harvest Penalty ($/yr)	Equipment Total ($/yr)	Penalty Total ($/yr)	Equipment & Penalty ($/yr)	Equipment & Penalty ($/ac)
1	15	15	600	1233	4198	0	1556	5431	1556	6987	11.65
2			1200	1867	6066	162	4510	7933	4672	12605	10.50
3			1800	2502	7933	18863	5907	10435	24770	35205	19.56
4			2400	3135	9800	52075	6067	12935	58142	71077	29.62
5	18	15	600	1308	4198	0	1556	5506	1556	7062	11.77
6			1200	1895	6066	0	4464	7961	4464	12425	10.35
7			1800	2480	7933	3306	7229	10413	10535	20948	11.64
8			2400	3065	9800	27030	8150	12865	35180	48045	20.02
9	24	15	600	1555	4198	0	1418	5753	1418	7271	11.95
10			1200	2143	6066	0	4293	8209	4293	12502	10.42
11			1800	2732	7933	182	7356	10665	7538	18203	10.11
12			2400	3321	9800	4408	10327	13121	14735	27856	11.61
13	30	15	600	1655	4198	0	1418	5853	1418	7271	12.12
14			1200	2162	6066	0	4196	8228	4196	12424	10.35
15			1800	2668	7933	0	7266	10601	7266	17867	9.93
16			2400	3174	9800	323	10509	12974	10832	23806	9.92

continued....

TABLE 21 continued...

Program No.	Seeding Width (feet)	Harvest Width (feet)	Farm Size (acre)	Seeding Cost ($/yr)	Harvest Cost ($/yr)	Seeding Penalty ($/yr)	Harvest Penalty ($/yr)	Equipment Total ($/yr)	Penalty Total ($/yr)	Equipment & Penalty ($/yr)	Equipment & Penalty ($/yr)
17	15	20	600	1233	4821	0	1512	6054	1512	7566	12.61
18			1200	1867	6408	162	4261	8275	4423	12698	10.58
19			1800	2502	7995	18863	5531	10497	24394	34891	19.38
20			2400	3135	9583	52075	5875	12718	57950	70668	29.45
21	18	20	600	1308	4821	0	1512	6129	1512	7641	12.74
22			1200	1895	6408	0	4024	8303	4024	12327	10.27
23			1800	2480	7995	3306	6702	10475	10008	20483	11.38
24			2400	3065	9583	27030	7873	12648	34903	47551	19.81
25	24	20	600	1555	4821	0	1423	6376	1423	7799	13.00
26			1200	2143	6408	0	3946	8551	3946	12497	10.41
27			1800	2732	7995	182	6766	10727	6948	17675	9.82
28			2400	3321	9583	4408	9918	12904	14326	27230	11.35
29	30	20	600	1655	4831	0	1423	6476	1423	7899	13.17
30			1200	2162	6408	0	3899	8570	3899	12469	10.39
31			1800	2668	7995	0	6621	10633	6621	17284	9.60
32			2400	3174	9583	323	10166	12757	10489	23246	9.69

TABLE 21 continued...

Program No.	Seeding Width (feet)	Harvest Width (feet)	Farm Size (acre)	Seeding Cost ($/yr)	Harvest Cost ($/yr)	Seeding Penalty ($/yr)	Harvest Penalty ($/yr)	Equipment Total ($/yr)	Penalty Total ($/yr)	Equipment & Penalty ($/yr)	Equipment & Penalty ($/ac)
33	15	30	600	1233	5555	0	1475	6788	1475	8263	13.77
34			1200	1867	6933	162	3609	8800	3771	12571	10.48
35			1800	2502	8311	18863	5460	10813	24323	35136	19.52
36			2400	3135	9689	52075	5257	12924	57332	70156	29.23
37	18	30	600	1308	5555	0	1475	6863	1475	8338	13.90
38			1200	1895	6933	0	3436	8828	3436	12264	10.22
39			1800	2480	8311	3306	6726	10791	10032	20823	11.57
40			2400	3065	9689	27030	7200	12754	34230	46984	19.58
41	24	30	600	1555	5555	0	1241	7110	1241	8351	13.92
42			1200	2143	6933	0	3248	9076	3248	12324	10.27
43			1800	2732	8311	182	6763	11043	6945	17958	9.99
44			2400	3321	9689	4408	8937	13010	13345	26355	10.98
45	30	30	600	1655	5555	0	1227	7210	1227	8437	14.06
46			1200	2162	6933	0	3192	9095	3192	12287	10.24
47			1800	2668	8311	0	6574	10979	6574	17553	9.75
48			2400	3174	9689	323	9021	12863	9344	22207	9.25

harvesting system versus a large harvesting system become insignificant as shown in Table 23. It should be noted that the cost comparisons, from the model, illustrated in Table 21, used the yearly basis for calculating depreciation on the harvest equipment.

TABLE 23. TOTAL ANNUAL COST OF SWATHER AND COMBINE

Farm Size (acres)	Harvest Equipment Size	Total Cost/Yr Depreciation Calculated Hourly Life-Time	Total Cost Depreciation Calculated Yearly Life-Time
600	small	4141	4198
	medium	4146	4821
	large	4235	5555
1200	small	7360	6066
	medium	7020	6408
	large	6831	6933
1800	small	10580	7933
	medium	9895	7995
	large	9425	8311
2400	small	13799	9800
	medium	12769	9583
	large	12020	9690

The results as shown in Table 21 indicate that there is some interaction between seeding equipment size and harvest equipment size:

(1) harvest penalties are reduced slightly when oversized seeding equipment is used;

(2) Undersized seeding equipment causes harvest penalties to appear relatively small on large acreages because the total

acreage seeded is actually less than the farm size.

From Table 21 the optimum seeding and harvesting machine size based on the minimum annual penalty and machine cost for the farm sizes studied are shown in Table 24.

TABLE 24. OPTIMUM MACHINERY SIZE RELATIVE TO FARM SIZE

Farm Size (acres)	Seeding Machine		Swather		Combine Capacity (ac/hr)
	Width (feet)	Capacity (ac/hr)	Width (feet)	Capacity (ac/hr)	
600	15	7.27	15	7.5	4
1200	18	8.73	20	10.0	6
1800	30	14.55	20	10.0	6
2400	30	14.55	30	15.0	8

Oversizing of equipment does not appear to create a significant penalty. The use of the largest seeding and harvesting equipment on all but the smallest acreage does not create a significant increase in cost compared to the optimum machinery selection above. From Table 21 it can be seen that the largest equipment on 1200 acres costs only 3 cents per acre per year more than the optimum above. Similarly, the largest equipment on 1800 acres costs only 15 cents per acre per year more than the optimum above.

7. CONCLUSIONS AND RECOMMENDATIONS

The traditional method of calculating depreciation on a yearly basis should be studied further. The model indicates that larger equipment is a sound investment if depreciation is calculated only on the hours of use. However, even when depreciation is calculated on a yearly basis, the penalty for oversizing is very small.

The criteria for harvesting should be studied further. Such parameters as wind, humidity, hours of sunlight, temperature as well as rainfall should be incorporated to establish more accurate work day predictions for harvesting. Improved accuracy in the harvesting section would make this model extremely meaningful.

The results of this simulation model should be compared to several years of actual farming data. With a sensitivity analysis and validation the results would be more definite. As it stands, the model is generous with good days during the harvesting season.

The results of the model are significant in that they indicate that there is no real penalty for oversizing seeding and harvesting equipment. This is especially true when noting that in this study the small equipment was given generous time to complete each operation. Also the small equipment had an economic advantage because conventional methods of cost calculations were used which under-charged the long annual hours on the small equipment and over-charged the low annual hours on the large equipment in terms of depreciation charges. From the farm manager's standpoint, another economic factor which should be considered is income tax. Since farm equipment is tax deductible, the extra money spent on larger equipment only costs some fraction of the face value depending on the individual income tax rate.

In summary, the model indicates that there is a definite penalty for farm equipment smaller than the optimum sizes given in Table 24. However, there is no significant economic advantage or disadvantage to sizing of farm equipment larger than these optimum sizes.

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APPENDIX A. FORTRAN SEEDING AND HARVESTING PROGRAM.

```
      COMMON PR(200),AR(200),C(50),D(200),R(200),S(50),H(50),M,A
      EQUIVALENCE (C(1),WAC),(C(2),WCD),(C(3),BAC),(C(4),BCD),(C(5),OAC)
     1,(C(6),OCD),(C(7),CCT),(C(8),OCT),(C(9),SDCD),(C(10),WACS),(C(11),
     1BACS),(C(12),OACS),(C(13),PEN),(C(14),WPEN),(C(15),BPEN),(C(16),OP
     1EN),(C(17),SPEN),(C(18),BACY),(C(19),OACY),(C(20),MDW),(C(21),MDB)
     1,(C(22),MDO),(C(23),WACY),
     1                 (S(1),SCC),(S(2),SOC),(S(3),SWCD),(S(4),SWPN),
     1(S(5),SBPN),(S(6),SOPN),(S(7),WAS),(S(8),BAS),(S(9),OAS),
     1(S(10),MDCW),(S(11),MDCB),(S(12),MDCO),
     1(H(1),CCC),(H(2),COC),(H(3),CBCD),(H(4),CWPN),(H(5),CBPN),(H(6),
     1COPN),(H(7),AWBA),(H(8),ABBA),(H(9),AOBA),(H(10),PWA),(H(11),PWB),
     1(H(12),PWC),(H(13),PBA),(H(14),PBB),(H(15),PBC),(H(16),PCA),
     1(H(17),POB),(H(18),POC),(H(19),WACB),(H(20),BACB),(H(21),OACB),
     1 (H(22),GD)
      REAL X(200,50),E(200)
      REAL*8 Y,YF,F
      DATA X/5000*0./
      IX=6555
      DO 1 I=1,50
      T=I*.01
      DO 2 J=1 ,200
      TX=J*.01
    2 E(J)=(EXP(-(TX-.005)/T)-EXP(-(TX+.005)/T))*100.
      DO 3 J=2,200
    3 E(J)=E(J)+E(J-1)
      DO 13 J=1,200
   13 E(J)=(100-E(J))/2.25+E(J)
      E(200)=100
      DO 4 J=1 ,200
    4 X(J,I)=0
      DO 1 J=2,200
      J1=E(J-1)+1
      J2=E(J)
      DO 1 K=J1,J2
      IF(X(K,I).GT.0) GOTO 1
      IF(J-200) 5,12,1
   12 IF(I.GT.30) GOTO 5
      X(K,I)=X((K-1),I)
      GOTO 1
    5 X(K,I)=J*.01
    1 CONTINUE
      READ(5,8)(PR(L),L=1,200)
      READ(5,8)(AR(L),L=1,200)
      READ(5,10)(C(JJ),JJ=1,17)
      READ(5,77)(S(KK),KK=1,6)
      READ(5,77)(H(MM),MM=1,18)
   77 FORMAT(10F8.2/8F8.2)
    8 FORMAT(20F4.3)
   10 FORMAT(10F8.2/7F8.2)
      A=10
      F=1.0/2147483647
      DO 88 M=1,100
      CT=0
      GD=1
      Q=0
      WACS=0.
      BACS=0.
```

```
      OACS=0.
      WACY=WAC
      BACY=BAC
      OACY=OAC
      WAS=0.
      BAS=0.
      OAS=0.
      WACB=0.
      BACB=0.
      OACB=0.
      IF(M-A)83,84,83
   84 WRITE(6,9)
    9 FORMAT('1'/' ',' DAY',T12,'AC OF WHT',T22,'AC OF BAR',T32,'AC OF
     1OAT',T44,'PENALTY',T54,'CAP COST',T65,'OP COST')
   83 DO 999 L=1,200
      IY=IX*65539
      IF(IY.LT.0) IY=IY+2147483647+1
      IX=IY
      YF=IY
      Y=YF*F
      R(L)=0
      IF(Y.GT.PR(L)) GOTO 100
      IY=IX*65539
      IF(IY.LT.0) IY=IY+2147483647+1
      IX=IY
      YF=IY
      Y=YF*F
      IYFL=Y*99+1
      IAR=AR(L)*100/PR(L)
      R(L)=X(IYFL,IAR)
  100 Z=R(L)
  999 CONTINUE
C****  CRITERIA FOR SEEDING
      DO 99 L=1,62
      IF(L.EQ.62) GOTO 7
C****  THE LAST SEEDING DATE MUST BE GOOD OR TABULATION WILL NOT RESULT
      Z=R(L)+Q
      IF(Z.GT.0.05) GOTO 20
      IF(L.LT.10) GOTO 6
C****  THIS STATEMENT ESTABLISHES EARLEAST SEEDING DATE AND UTILIZES PREV
C****  RAINFALL DATA TO DETERMINE IF SEEDING CAN START ON THAT DATE
    7 D(L)=1
      Q=0
      GO TO 99
   20 IF(Z.GT.0.25) GOTO 30
    6 D(L)=0
      Q=0
      GOTO 99
   30 IF(Z.GT.0.5) GOTO 40
      D(L)=0
      Q=.20
      GOTO 99
   40 IF(Z.GT.1.0) GOTO 50
      D(L)=0
      Q=.45
      GOTO 99
   50 IF(Z.GT.2.0) GOTO 60
      D(L)=0
      Q=.95
      GO TO 99
```

```
   60 D(L)=0
      Q=1.95
   99 CONTINUE
      DO 70 L=1,62
      IF(D(L).EQ.0) GOTO 70
      CALL SEED(L)
   70 CONTINUE
      IF(M-A)81,82,81
   82 WRITE(6,34)
   34 FORMAT('1'/' ',' DAY',T12,'WHT SWATH',T22,'BAR SWATH',T32,'OAT SW
     1ATH',T42,'PENALTY',T54,'CAP COST',T65,'OP COST')
   81 Q=0
      DO 71 L=63,200
C**    CRITERIA FOR SWATHING
      Z=R(L)+Q
      IF(Z.GT.0.05) GOTO 120
      D(L)=1
      Q=0
      GOTO 71
  120 IF(Z.GT.0.25) GOTO 130
      D(L)=0
      Q=0
      GOTO 71
  130 IF(Z.GT.0.5) GOTO 140
      D(L)=0
      Q=.20
      GOTO 71
  140 IF(Z.GT.1.0) GOTO 150
      D(L)=0
      Q=.45
      GOTO 71
  150 IF(Z.GT.2.0) GOTO 160
      D(L)=0
      Q=.95
      GOTO 71
  160 D(L)=0
      Q=1.95
   71 CONTINUE
      DO 72 L=63,200
      IF(L.EQ.200) GOTO 333
      IF (D(L).EQ.0) GOTO 72
 333  CALL SWATH(L)
  72  CONTINUE
      Q=0
      CT=0
      IF(M-A)75,28,75
   28 WRITE(6,33)
   33 FORMAT('1'/' ',' DAY',T12,'WHT COMB',T22,'BAR COMB',T32,'OAT COMB
     1',T42,'PENALTY',T54,'CAP COST',T65,'OP COST')
  75  DO 73 L=63,200
C**   CRITERIA FOR COMB
      IF(L.EQ.200) GOTO 334
      Z=R(L)+Q
      IF(MDW.GT.L) GOTO 29
      IF(Z.LE.0.01) GOTO 29
      CT=CT+1
      IF(CT-3)31,35,36
   31 GD=1
      GOTO 29
   35 GD=2
```

```
      GOTO 29
   36 IF(CT.GT.4) GOTO 37
      IF(R(L).GE.0.01) GOTO 37
      GD=2
      GOTO 29
   37 GD=3
   29 IF(Z.GT.0.01) GOTO 23
      D(L)=1
  334 CALL CCMB(L)
      Q=0
      GOTO 73
   23 IF(Z.GT.0.15) GOTO 24
      D(L)=0
      Q=0
      GOTO 73
   24 IF(Z.GT.0.35) GOTO 25
      D(L)=0
      Q=.06
      GOTO 73
   25 IF(Z.GT.0.55) GOTO 26
      D(L)=0
      Q=.16
      GOTO 73
   26 IF(Z.GT.0.75) GOTO 27
      D(L)=0
      Q=.36
      GOTO 73
   27 D(L)=0
      Q=.55
   73 CONTINUE
      IF(M-A)88,89,88
   89 A=A+10
   88 CONTINUE
      STOP
      END
      SUBROUTINE SEED(L)
      COMMON PR(200),AR(200),C(50),D(200),R(200),S(50),H(50),M,A
      EQUIVALENCE (C(1),WAC),(C(2),WCD),(C(3),BAC),(C(4),BCD),(C(5),OAC)
     1,(C(6),OCD),(C(7),CCT),(C(8),OCT),(C(9),SDCD),(C(10),WACS),(C(11),
     1BACS),(C(12),OACS),(C(13),PEN),(C(14),WPEN),(C(15),BPEN),(C(16),OP
     1EN),(C(17),SPEN),(C(18),BACY),(C(19),OACY),(C(20),MDW),(C(21),MDB)
     1,(C(22),MDO),(C(23),WACY),
     1                  (S(1),SCC),(S(2),SOC),(S(3),SWCD),(S(4),SWPN),
     1(S(5),SBPN),(S(6),SOPN),(S(7),WAS),(S(8),BAS),(S(9),CAS),
     1(S(10),MDCW),(S(11),MDCB),(S(12),MDCO),
     1(H(1),CCC),(H(2),CCC),(H(3),CBCD),(H(4),CWPN),(H(5),CBPN),(H(6),
     1COPN),(H(7),AWBA),(H(8),ABBA),(H(9),AOBA),(H(10),PWA),(H(11),PWB),
     1(H(12),PWC),(H(13),PBA),(H(14),PBB),(H(15),PBC),(H(16),POA),
     1(H(17),POB),(H(18),POC),(H(19),WACB),(H(20),BACB),(H(21),OACB),
     1 (H(22),GD)
      IF(WACS.GE.WACY) GOTO 3
      IF(L.GT.WCD) GOTO 4
      IF(WACS.GT.0) GOTO 10
      MDW=L+95
C***  MATURATION DATE ESTABLISHED FROM FIRST SEEDING DATE
   10 WACS=WACS+SDCD
      IF(WACY.GT.WACS) GOTO 5
      WACS=WACY
C***  TO AVOID SEEDING MORE THAN ACREAGE TO BE SEEDED
      GO TO 5
```

```
    4 SPEN=SPEN+WPEN*(WACY-WACS)
      BACY=BACY+WACY-WACS
      WACY=WACS
    3 IF(BACS.GE.BACY) GOTO 13
      IF(L.GT.BCD) GOTO 14
      IF(BACS.GT.0) GOTO 11
      MDB=L+87
   11 BACS=BACS+SDCD
      IF(BACY.GT.BACS) GOTO 5
      BACS=BACY
      GOTO 5
   14 SPEN=SPEN+BPEN*(BACY-BACS)
      OACY=OACY+BACY-BACS
      BACY=BACS
   13 IF(OACS.GE.OACY) GO TO 5
      IF(L.GT.OCD) GOTO 114
      IF(OACS.GT.0) GOTO 12
      MDO=L+90
   12 OACS=OACS+SDCD
      IF(OACY.GT.OACS) GOTO 5
      OACS=OACY
      GOTO 5
  114 SPEN=SPEN+OPEN*(OACY-OACS)
      OACY=OACS
    5 IF(M-A)20,6,20
    6 WRITE(6,9)L,WACS,BACS,OACS,SPEN,CCT,OCT
    9 FORMAT(' ',I5,T12,6F10.2)
   20 RETURN
      END
      SUBROUTINE SWATH(L)
      COMMON PR(200),AR(200),C(50),D(200),R(200),S(50),H(50),M,A
      EQUIVALENCE (C(1),WAC),(C(2),WCD),(C(3),BAC),(C(4),BCD),(C(5),OAC)
     1,(C(6),OCD),(C(7),CCT),(C(8),OCT),(C(9),SDCD),(C(10),WACS),(C(11),
     1BACS),(C(12),OACS),(C(13),PEN),(C(14),WPEN),(C(15),BPEN),(C(16),OP
     1EN),(C(17),SPEN),(C(18),BACY),(C(19),OACY),(C(20),MDW),(C(21),MDB)
     1,(C(22),MDO),(C(23),WACY),
     1                    (S(1),SCC),(S(2),SOC),(S(3),SWCD),(S(4),SWPN),
     1(S(5),SBPN),(S(6),SOPN),(S(7),WAS),(S(8),BAS),(S(9),OAS),
     1(S(10),MDCW),(S(11),MDCB),(S(12),MDCO),
     1(H(1),CCC),(H(2),COC),(H(3),CBCD),(H(4),CWPN),(H(5),CBPN),(H(6),
     1COPN),(H(7),AWBA),(H(8),ABBA),(H(9),AOBA),(H(10),PWA),(H(11),PWB),
     1(H(12),PWC),(H(13),PBA),(H(14),PBB),(H(15),PBC),(H(16),POA),
     1(H(17),POB),(H(18),POC),(H(19),WACB),(H(20),BACB),(H(21),OACB),
     1 (H(22),GD)
      IF(L.EQ.200) GOTO 8
      IF(WAS.GE.WACS) GOTO 3
      IF(MDW.GT.L) GOTO 3
      IF(WAS.GT.0) GOTO 1
      MDCW=L+7
C****  MATURATION DATE FOR COMBINING IS DETERMINED BY INITIAL SWATHING DA
    1 WAS=WAS+SWCD
      IF(WAS.LT.WACS)GOTO 4
      WAS=WACS
C****  TO AVOID SWATHING MORE ACRES THAN SEEDED TOWHT
      GOTO 4
    3 IF(BAS.GE.BACS) GOTO 5
      IF(MDB.GT.L) GOTO 5
      IF(BAS.GT.0) GOTO 2
      MDCB=L+5
    2 BAS=BAS+SWCD
```

```
      IF(BAS.LT.BACS)GOTC 4
      BAS=BACS
C****  TO AVOID SWATHING MORE ACRES THAN SEEDED TO BARLEY
      GOTO 4
    5 IF(OAS.GE.OACS) GOTO 4
      IF(MDO.GT.L) GOTO 4
      IF(OAS.GT.0) GOTO 6
      MDCO=L+4
    6 OAS=OAS+SWCD
      IF(OAS.LT.OACS)GOTC 4
      OAS=OACS
C****  TO AVOID SWATHING MORE ACRES THAN SEEDED TO OATS
      GOTO 4
    8 PEN=PEN+((WACS-WAS)*SWPN)+((BACS-BAS)*SBPN)+((OACS-OAS)*SOPN)
    4 IF(M-A)20,7,20
    7 WRITE(6,9)L,WAS,BAS,OAS,PEN,SCC,SOC
    9 FORMAT (' ',I5,T12,6F10.2)
   20 RETURN
      END
      SUBROUTINE COMB(L)
      COMMON PR(200),AR(200),C(50),D(200),P(200),S(50),H(50),M,A
      EQUIVALENCE (C(1),WAC),(C(2),WCD),(C(3),BAC),(C(4),BCD),(C(5),OAC)
     1,(C(6),OCD),(C(7),CCT),(C(8),OCT),(C(9),SDCD),(C(10),WACS),(C(11),
     1BACS),(C(12),OACS),(C(13),PEN),(C(14),WPEN),(C(15),BPEN),(C(16),OP
     1EN),(C(17),SPEN),(C(18),BACY),(C(19),OACY),(C(20),MDW),(C(21),MDB)
     1,(C(22),MDO),(C(23),WACY),
     1                   (S(1),SCC),(S(2),SOC),(S(3),SWCD),(S(4),SWPN),
     1(S(5),SBPN),(S(6),SOPN),(S(7),WAS),(S(8),BAS),(S(9),OAS),
     1(S(10),MDCW),(S(11),MDCB),(S(12),MDCO),
     1(H(1),CCC),(H(2),CCC),(H(3),CBCD),(H(4),CWPN),(H(5),CBPN),(H(6),
     1COPN),(H(7),AWBA),(H(8),ABBA),(H(9),AOBA),(H(10),PWA),(H(11),PWB),
     1(H(12),PWC),(H(13),PBA),(H(14),PBB),(H(15),PBC),(H(16),POA),
     1(H(17),POB),(H(18),POC),(H(19),WACB),(H(20),BACB),(H(21),OACB),
     1 (H(22),GD)
      IF(L.EQ.200) GOTO 22
      IF(WACB.GE.WAS) GOTO 13
      IF(MDCW.GT.L) GOTO 13
      WACB=WACB+CBCD
      IF(GD-2)1,2,3
    2 PEN=PEN+CBCD*AWBA*(PWA-PWB)
      GOTO 1
    3 PEN=PEN+CBCD*AWBA*(PWA-PWC)
    1 IF(WACB.LT.WAS)GOTC 14
      WACB=WAS
C****  TO AVOID COMBINING MORE ACRES THAN SWATHED
      GOTO 14
   13 IF(BACB.GE.BAS) GOTO 15
      IF(MDCB.GT.L) GOTO 15
      BACB=BACB+CBCD
      IF(GD-2)4,5,6
    5 PEN=PEN+CBCD*ABBA*(PBA-PBB)
      GOTO 4
    6 PEN=PEN+CBCD*ABBA*(PBA-PBC)
    4 IF(BACB.LT.BAS) GOTO 14
      BACB=BAS
C****  TO AVOID COMBINING MORE ACRES THAN SWATHED
      GOTO 14
   15 IF(OACB.GE.OAS) GOTO 14
      IF(MDCO.GT.L) GOTO 14
      OACB=OACB+CBCD
```

```
      IF(GD-2)7,8,10
    8 PEN=PEN+CBCD*AOBA*(POA-POB)
      GOTO 7
   10 PEN=PEN+CBCD*AOBA*(POA-POC)
    7 IF(OACE.LT.OAS) GOTO 14
      OACB=OAS
C****  TO AVOID COMBINING MORE ACRES THAN SWATHED
      GOTO 14
   22 PEN=PEN+((WAS-WACB)*CWPN)+((BAS-BACB)*CBPN)+((OAS-OACB)*COPN)
   14 IF(M-A)20,11,20
   11 WRITE(6,9)L,WACB,BACB,OACB,PEN,CCC,CCC
    9 FORMAT (' ',I5,T12,6F10.2)
   20 RETURN
      END
```

APPENDIX B. INPUT PARAMETERS OF THE MODEL.

ABBA	average yield in bushels per acre for crop 2
AOBA	average yield in bushels per acre for crop 3
AR	average rainfall in inches for a given day
AWBA	average yield in bushels per acre for crop 1
BAC	acres to be seeded to crop 2
BCD	last date for seeding crop 2
CBCD	combine capacity acres per day
CBPN	penalty dollars per acre for crop 2 not combined
CCC	total capital cost per year for combining
CCT	total capital cost per year for seeding
COPN	penalty dollars per acre for crop 3 not combined
CWPN	penalty dollars per acre for crop 1 not combined
OAC	acres to be seeded to crop 3
OCD	last date to seed crop 3
OCT	total operating cost, dollars per year for seeding
PBA	price dollars per bushel for crop 2 grade 1
PBB	price dollars per bushel for crop 2 grade 2
PBC	price dollars per bushel for crop 2 grade 3
POA	price dollars per bushel for crop 3 grade 1
POB	price dollars per bushel for crop 3 grade 2
POC	price dollars per bushel for crop 3 grade 3
PR	probability of rainfall on a given day
PWA	price dollars per bushel for crop 1 grade 1
PWB	price dollars per bushel for crop 1 grade 2
PWC	price dollars per bushel for crop 1 grade 3
SCC	total capital cost per year for swathing
SDCD	seeding capacity in acres per day
SOC	total operating cost per year for swathing
SWCD	swather capacity in acres per day
WAC	acres to be seeded to crop 1
WCD	last date for seeding crop 1

APPENDIX C. INTERNAL PARAMETERS OF THE MODEL.

BACY	acres to be seeded to crop 2 initially (stored value)
C	seeding parameters
CT	bad day counter after maturation date to determine grade
D	Y-axis for rainfall array
H	combining parameters
OACY	acres to be seeded to crop 3 initially (stored value)
Q	amount of soil moisture at the start of each day
R	X-axis for rainfall array
S	swathing parameters
T	mean daily rainfall in inches
TX	expected rainfall in inches
WACY	acres to be seeded to crop 1 initially
Z	moisture condition of soil after a rainfall

APPENDIX D. OUTPUT PARAMETERS OF THE MODEL.

BACB	acres of crop 2 to be combined
BACS	total acres seeded to crop 2 on a given day
BAS	acres of crop 2 to be swathed
BPEN	penalty dollars per acre for not completing crop 2 seeding
GD	grade of grain
MDCB	maturation date for combining crop 2
MDCO	maturation date for combining crop 3
MDCW	maturation date for combining crop 1
MDB	maturation date for swathing crop 2
MDO	maturation date for swathing crop 3
MDW	maturation date for swathing crop 1
OACB	acres of crop 3 to be combined
OACS	acres seeded to crop 3 on a given day
OAS	acres of crop 3 to be swathed
OPEN	penalty, dollars per acre for not seeding crop 3
PEN	total penalty in dollars
SBPN	penalty, dollars per acre for not swathing crop 2
SOPN	penalty, dollars per acre for not swathing crop 3
SWPN	penalty, dollars per acre for not swathing crop 1
WACB	acres of crop 1 to be combined
WACS	total acres seeded to crop 1 on a given day
WAS	acres of crop 1 to be swathed
WPEN	penalty, dollars per acre for not seeding crop 1

APPENDIX E. RAINFALL SIMULATION PROCEDURE.

Line	
19	Initial do-loop for rainfall matrix with average rainfall and accumulative probability as co-ordinates.
20	T is assigned the average rainfalls as do-loop progresses (0.01 to 0.50 inches).
21	Start of do-loop to establish rainfall amounts and calculate probabilities for each amount corresponding to each average rainfall.
22	TX is assigned the rainfall amounts (0.01 to 2.00 inches).
23	The probability in percent of each rainfall amount is calculated for each average rainfall.
24 & 25	Do-loop to calculate the accumulative probabilities for each rainfall amount in each average rainfall category.
26 & 27	Do-loop to correct accumulative probabilities to fit actual data comparison.
28	Final accumulative probability is given the value 100% instead of the calculated 99.999.
29 & 30	Do-loop to initialize matrix 50 x 200 to zero.
31	Do-loop to provide the accumulative probability co-ordinate for the matrix displaying rainfall amounts.
32	J1 is set equal to the accumulative probability for each rainfall amount (0.01 to 2.00). 1 is added on to eliminate the problem of a zero character in a DO statement.
33	J2 is set equal to the accumulative probability for each rainfall one increment above J1.
34	Do-loop running from J1 to J2 to establish rainfall amounts for accumulative probabilities between J1 and J2 inclusive.
35	If-statement to prevent duplication of established rainfall amounts.
36	If-statement used to: (1) transfer control to line 40 if rainfall amount has not been entered in the matrix location; (2) transfers control to line 37 if rainfall amount is to be entered into the last matrix location; (3) transfer control to line 41 if all matrix locations are full.
37	If-statement to transfer control to line 40 if the average rainfall is greater than 0.30 inches (for last matrix location only).

Line

38 If the average rainfall is less than 0.30 inches then the last rainfall amount is equal to the previous rainfall amount for the same average rainfall.

39 Transfer control to line 41.

40 Rainfall amount is calculated for particular location in the matrix (other than last position).

41 End of generated matrix for rainfall amounts with co-ordinates average rainfall and accumulative probability.